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The National Bureau of Standards Office of Recycled Materials 1976-1982

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The National Bureau of Standards Office of Recycled Materials 1976-1982

U.S. Department of Commerce
National Bureau of Standards

The National Bureau of Standards Office of Recycled Materials 1976-1982

Harvey Yakowitz, Editor

Office of Recycled Materials
National Bureau of Standards
Washington, D.C. 20234

Final Report of Activities and Accomplishments Pursuant to the Mandates of Section 383C of the Energy Policy Conservation Act and to the Mandates of Subtitle E of the Resource Conservation and Recovery Act

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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Purpose of the Report

This Report summarizes the activities and accomplishments of the Office of Recycled Materials of the National Bureau of Standards (NBS/ORM) undertaken in response to legislative directives from 1976 through 1982 and provides a compilation of FY 1982 activities of NBS/ORM.

During its six and one-half year lifetime, NBS/ORM fulfilled virtually all of the legislative directives with which NBS was charged. Waste oil and other materials destined for waste were the subject of requirements for test method development, evaluation and subsequent production of standards and guidelines for specifications. More than 125 publications and reports remain as a tangible legacy of NBS/ORM. In addition, the methods and standards developed under the guidance of NBS/ORM have been adopted throughout the recycling community. This report places major NBS/ORM activities in perspective and provides a point of embarkation for anyone wishing to utilize or adapt NBS/ORM results. In addition, the Report indicates that NBS fulfilled the legislative requirements in a timely, accurate, and efficient manner.

Acknowledgments

Literally hundreds of persons contributed to the results produced by NBS/ORM. The prime movers of NBS/ORM were Donald A. Becker, Manager of the Recycled Oil Program of NBS/ORM, Joseph Berke, Manager of the Recycled Materials Program from late 1977 to mid-1981, Dr. Eugene S. Domalski, Manager of the Recycled Materials Program from mid-1981 to October, 1982, and Mrs. R. T. Matthews, Manager of the NBS/ORM Technical Advisory Center from its inception to the end of FY 1982. The Administrative foundation on which NBS/ORM rested was entrusted to Mrs. V. M. Davis and Mrs. A. Marinoff in the 80's and to Mrs. R. D. Graham and Mrs. H. A. Hurd in the 70's. Mrs. A. Epstein served as Fiscal Aide from 1980-1982; Mrs. M. DeWese carried out this function from April, 1982 to December, 1982. Without the dedicated help of these key people, NBS/ORM could not have functioned.

With respect to this Report, Section III was prepared by Mr. Becker, Section IV.(3)b.1 through IV.(3)b.3 was prepared by Dr. Domalski, Section IV.(3)b.4 was prepared by Dr. A. Macek, Section IV.(3)c by Drs. W. Tsang and W. Shaub, Sections IX.(3) through IX.(5) by Mr. R. Chapman, Section IX.(8)a was prepared by Mr. T. Lettes of MBDA. Where appropriate, authors names are shown for the various Appendices. The remainder of the Report was written and compiled by Dr. Harvey Yakowitz, Chief NBS/ORM; he also edited the entire Report.

Note that the entire text was typed by the Text-Editing Facility of the NBS National Measurement Laboratory. The patience, forbearance, and excellent performance of this group is gratefully acknowledged.

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EXECUTIVE SUMMARY

During the Congressional deliberations which led to the passage of the Resource Conservation and Recovery Act of 1976 (RCRA, Public Law 94-580), Congress perceived the need for a research and development effort which would be independent of agencies given regulatory authority under the Act. Since the lead agency was to be the Environmental Protection Agency (EPA), the Congress sought another department of the U.S. government which would have experience and credibility in the measurement methods and techniques necessary to classify and characterize society's discards.

Congress elected to insert into the Act a separate Subtitle E assigning to the Secretary of Commerce several duties with respect to resource recovery. Specifically, the duties of the Secretary of Commerce are as follows:

- provision of guidelines for specifications for recovered materials;
- market development stimulation for these materials;
- promotion of proven technology; and
- a forum for the exchange of both technical and economic data relating to resource recovery facilities--presumably high-technology plants designed to recover materials and/or energy from waste.

In order to implement all of these responsibilities, the Secretary of Commerce delegated the necessary authority to accomplish the task to the National Bureau of Standards (NBS). Indeed, Section 5002 of RCRA states that the Secretary act through NBS in order to establish guidelines and specifications for materials which could be recovered from waste originally destined for disposal. In addition, NBS was directed to cooperate with voluntary consensus standards organizations, such as ASTM, and to work with other federal agencies in carrying out the mandates of the law.

FORMATION OF THE OFFICE OF RECYCLED MATERIALS

The NBS resource recovery program was formally established in November 1976. In 1978, the program was expanded to encompass NBS responsibilities under the Energy Policy and Conservation Act of 1975 (EPCA, Public Law 94-163), which requires NBS to determine the substantial equivalency of used and virgin oils. The work on recycled materials in response to Subtitle E of RCRA and the Recycled Oil Program was combined into the Office of Recycled Materials. In late 1979, NBS added a Technical Advisory Center, charged with the responsibility of determining the geographic location of markets for recycled materials and with developing an economic and technical database describing resource recovery systems.

The NBS Office of Recycled Materials staff recognized from the outset that recovering any materials from a waste destined for disposal was possible, but purposeless unless a market could be found for the recovered material. Therefore, materials to be recovered had to be marketable at a price which made recovery economically useful. The Office of Recycled Materials (ORM) examined the market for materials that could be recovered from wastes.

RECYCLED OIL PROGRAM

The NBS Recycled Oil Program was established in 1976, in direct response to passage of the Energy Policy and Conservation Act of 1975 (EPCA, Public Law 94-163; 42 U.S.C. 6201 et seq.), Section 383(3) of this law requires NBS to "...develop test procedures for the determination of substantial equivalency of re-refined or otherwise processed used oil or blend of oil ... with new oil for a particular end use."

The stated goal of the Recycled Oil Program was to provide the measurement methods and standards required for effective utilization of recycled petroleum products. This goal was achieved through:

- establishing the scientific and technical basis for characterization of recycled petroleum products;
- developing and evaluating test procedures for establishing the substantial equivalency between recycled and virgin petroleum products; and,
- providing technical information and support for the effective utilization of recycled petroleum products.

These goals were implemented through research and development activities both within NBS and at several outside institutions. Details of accomplishments can be found in Section III.

RECYCLED MATERIALS PROGRAM

The NBS program was formally established in November 1976. In 1979, NBS added a Technical Advisory Center, charged with the responsibility for assisting in the determination of the geographic location of markets for recycled materials and with developing an economic and technical database describing resource recovery systems.

With regard to municipal solid waste (MSW), the basic constituents are an organic fraction consisting of such items as newsprint, other paper fibers, grass clippings, and other garbage (waste food). By weight, this fraction comprises about 80 percent of MSW. The remaining 20 percent consists of glass (12 percent) and metal consisting of ferrous discards (7 percent) and aluminum, primarily from beverage containers (1 percent). These percentages are based on national averages developed under a study sponsored by the

Environmental Protection Agency. The United States produces approximately 140 million tons per year of MSW; this figure has not changed appreciably in the past five to seven years. In examining the marketability of the various fractions of MSW, staff of ORM found that aluminum marketed very well without governmental support. Therefore, there was no need to utilize Federal research funds to aid in the marketability of aluminum, and ORM has done no work on the aluminum fraction. With regard to the ferrous fraction, the most salient piece of research which concerned the effect of impurities such as copper and tin on the marketability of ferrous material, was carried out by the National Center for Resource Recovery under a National Academy of Sciences grant at about the time ORM was formed. We saw no need to duplicate this research, and therefore have done little research on the ferrous fraction. In most case, the marketability of the ferrous fraction has followed the market fluctuation for No. 2 dealer scrap bundles.

The glass fraction usually appears as broken glass rather than as separated bottles or other containers. Since glass is manufactured in three basic colors--amber, green, and flint (or clear)--color mixture is of great importance to the manufacturers of glass products. Furthermore, in the manufacture of glass, non-melting components, such as ceramics, are of crucial importance since these unwanted components can reduce the strength of the glass container or seriously mar its appearance, or both. Thus, for very good commercial reasons, manufacturers of glass products are extremely careful about the raw materials they will allow in the glass furnaces or tanks. Specifications for including post-consumer waste glass in the glass container manufacturing process were nearly exclusionary prior to research on the properties of the glass fraction. Therefore, NBS carried out a research program aimed at characterizing post-consumer waste glass for potential introduction into a glass tank. As a result of NBS research, the present ASTM specification is less restrictive than in the past.

The organic fraction is the most difficult to market, since at first consideration, who wants to buy garbage? But, the organic fraction will burn, and if the incinerator in which it is burned is appropriately configured, energy can be recovered and the atmosphere not polluted. Thus, the organic fraction can be destroyed, energy from it recaptured, and the environment not damaged. Very little was known in 1976 about the characteristics of MSW as a fuel or about processing the organic fraction of MSW to create what is known as refuse-derived fuel. Therefore, a major portion of the NBS research program relating to MSW was devoted to characterizing the organic fraction. In addition, there was a second question: If one separates fibers such as newsprint from the organic fraction, will that action affect the economics of a resource recovery facility or, the reverse, if the paper is taken to the incinerator, will paper recyclers be driven out of business? Through the efforts of the Bureau of Industrial Economics (DOC), we have released a study of wastepaper markets in four States (Florida, Georgia, and North and South Carolina). The survey indicates a growth in demand for waste newspaper and includes a directory of waste newspaper markets, as well as cellulose insulation demand.

NBS research has addressed all of these issues and, many of the research results on refuse-derived fuels have been transferred to the public in conjunction with ASTM Committee E-38 on resource recovery. Indeed, NBS/ORM research has contributed substantially to fifteen standards published in the ASTM annual book of standards. Examples of specific NBS research include the following:

1) Provision of consensus test methods for determining the heating value of minimally processed refuse so that engineers can evaluate the performance and design specifications of an incinerator or boiler.

   o Finding: In aid of these goals, NBS has demonstrated that one-kilogram-size samples of refuse can be burned in flowing oxygen; the characteristics of this process have been completely characterized.

2) Provision of test methods for determining the heating value of refuse-derived-fuel so that it can be established as an article of commerce.

   o Finding: In cooperation with ASTM, heating values of various refuse-derived-fuels have been determined; the measurement method can be widely adopted.

3) Development of thermo-analytical test methods for characterizing refuse-drived-fuels.

   o Finding: Thermo-analytical test methods provide a fingerprint of a refuse-derived-fuel sample, and have applications in quality control related to processing, handling, and up-grading refuse-derived-fuels.

4) NBS is developing a definitive body of data on the physical and chemical properties of fossil fuel residues from a variety of combustion systems. The data, protocols, and test methods which are being developed will aid in the environmental management of waste streams from coal combustion and other fossil energy conversion processes. Note that this work is being carried out in cooperation with the Department of Energy.

   o Finding: An NBS Standard Reference Material representing fly ash has been characterized.

5) Examination of the available physical and chemical properties of selected hazardous waste components and utilize these data to develop practical predictive schemes for various properties.

- o Finding: NBS has developed a procedure for estimating the heats of formation of aromatic compounds, including chlorinated benezenes, phenols, and dioxins.

6) Development of test methods for the determination of trace metallic components in solid waste and recycled materials.

- o Finding: NBS was able to prepare a synthetic leachate reference material containing known concentrations of inorganic priority pollutants; this leachate is being used throughout the U.S. in order to characterize hazardous waste extraction procedures.

7) Development of test methods for the quantitative analysis of trace organic constituents in recycled materials.

- o Finding: NBS has developed a method to analyze for the presence of trace amounts of PCBs in an oil base; unless it can be shown that PCBs are not present, such recycled oils cannot be marketed.

These are only a few examples of NBS laboratory research on recycled materials. Details are discussed in Sections III through VI and VIII and in the publications listed in Appendix I.

As a further effort toward improving markets for recovered materials, Subtitle F of RCRA mandates the Federal Government and other governmental entities which utilize Federal funds to procure the maximum practicable amount of recyclables in what they purchase. ORM, in cooperation with seven States--Colorado, Florida, Michigan, Minnesota, New Jersey, New York, and Washington--and, the National Association of State Purchasing Officers, produced a multivolume study entitled "Procurement of Products Containing Recovered Material: A Summary of Activities in Seven States." These reports deal with supply and demand problems associated with government procurement of recyclables. Section VII contains details.

The Technical Advisory Center (TAC) of NBS/ORM was established to provide a framework for fostering the advances required to optimize both economic and environmental factors associated with recovery and/or reuse of resources contained in solid wastes. The TAC accomplished these goals by developing methodologies for the economic assessment of current and potential technologies, market potentials, as well as identifying institutional barriers to resource conservation and recovery; to assist public and private sector to utilize the methodologies and information; and, by identifying the potential for new business opportunities and growth. TAC's primary function was to help to assure implementation of RCRA responsibilities for the Department, which are 1) encouragement of the commercialization of proven technology; 2) stimulation of the development of markets for recovered materials, and 3) evaluation of the commercial feasibility of resource recovery facilities as well as the development of an information base to assist communities and other entities in selection of a recovery system.

NBS/ORM explored the feasibility of developing a Resource Recovery Planning (RRPLAN) model design for economic evaluation of resource recovery systems on a regional or statewide basis. A study sponsored by NBS/ORM concluded that a gross design of a mathematical model to serve the following purposes was possible:

1) Generation of a preferred regional plan for resource recovery;

2) evaluation of a specified plan for resource recovery; and,

3) provision for the inclusion of source separation as an option.

The criteria selected for generating a preferred regional plan for resource recovery were:

- o Minimize lifetime cost of a selected plan; or
- o minimize lifetime discounted cost; or
- o maximize net energy balance; or,
- o optimize a composite of weighted cost and/or energy considerations.

NBS/ORM staff cooperated with both State and local governmental entities in development of case studies. See Section IX for details. Section IX also provides an analysis of uncertainties associated with the model and with the input data.

RRPLAN, if used properly, provides the foundation for planning. But considerable additional assessment may well be necessary in order to choose the proper strategy for a given region. This assessment involves probabilistic estimation for the input variables (discount rate, costs, etc.) followed by multiple RRPLAN evaluations. [The results will provide values for all terms in equations (IX-12) and (IX-16).] Unless all of these steps are taken, RRPLAN results need to be treated with extreme caution.

RRPLAN, as developed for and by NBS/ORM, represents an appropriate means to begin evaluation of specific resource recovery options for a city, state or region. The input data requirements will tend to require the prospective RRPLAN client to determine as accurately as possible each item of data. If these data are not properly obtained, the risks of adopting a resource recovery plan become much greater; the U.S. has had several cases where resource recovery options have not lived up to proponents expectations. Careful data assessment, RRPLAN and solutions to equations (IX-12) and (IX-16) should help to reduce the risk associated with resource recovery.

In turn, the data gathering process and the subsequent RRPLAN and probabilistic analysis should clearly highlight potential or actual institutional problems.

RRPLAN can be applied to recovery of hazardous or non-hazardous industrial waste with some modifications. Thus, all waste classes which were dealt with by RCRA can be taken into account. The preceding general assessment is true for all classes of waste.

The Resource Recovery Committee of the Association of State and Territorial Solid Waste Management Officials under terms of an NBS/ORM grant submitted the report States' Measurement Needs. The report consists of the following sections:

- o Part I: Final Report and Executive Summary: State summary charts depicting definitions of hazardous waste, measurement parameters, laboratory needs, and available training programs; Conclusions and Recommendations.
- o Part II: State Profiles (Texas, Louisiana, Oklahoma, Pennsylvania, New York, Mississippi, Virginia): Solid waste, hazardous waste and resource recovery program objectives; State agency organizational make-up; resources and manpower; selected regulations; data from field visits on laboratory capability; other appropriate documentation.
- o Part III: Analytical Operations Procedure Manual Model: A cohesive technical framework and outline of tools necessary to augment States' hazardous waste program based on experience and guidance of State of Louisiana.

In preparing this Final Report on Part 2, the Association's Resource Recovery Committee considered the following questions:

1) Does the State have adequate laboratory support staff, equipment, and resources or the services of a private contractor to perform RCRA-related measurement activities?

2) What are State laboratory equipment holdings?

3) Are the laboratories certified? Do they have a quality assurance program?

4) Is there adequate laboratory and field protective equipment and clothing?

5) What types of technical assistance do laboratory and field personnel need and from which entities?

6) What are the overall prioritized needs in support of implementing the technical requirements under RCRA?

The Committee concluded that even though State programs vary in stringency of regulatory requirements, State measurement needs are similar in hazardous waste. However, Subtitle D resource recovery measurement needs, while identified, do not exhibit the same level of priority associated with the Subtitle C - Hazardous waste program. Nevertheless, standard analytical methods, protocols, and procedures specified in State regulations match those methods cited in Federal criteria. Development of standard laboratory and field methods for sampling and analyses as well as standard reference data are required. The lack of availability for such measurement tools is severely impeding national consistency on a State-to-State basis, timely program implementation, and worker protection and safety. Consequently, a formal operating procedures manual is necessary to assure not only State-to-State programmatic and enforcement consistency, but also in intra-State field and functional laboratory activities. A standard laboratory certification quality assurance program does not exist but would be helpful in attaining State-to-State consistency. Lastly, training programs and technical assistance for laboratory and field personnel are deficient at State level. Section VIII contains details.

Throughout FY 1981, the Great Lakes Basin Commission conducted a study to develop methodologies for estimating the economic development effects of hazardous waste management and to assess the potential for resource recovery of materials from selected waste streams. The three industrial and manufacturing, activities selected as case studies were: steel manufacturing, electroplating, and paint manufacturing. This study commenced September 1980 and was scheduled for completion by May 1982. However, the Great Lakes Basin Commission expired September 1981. After that date, the Michigan Department of Commerce worked to complete this study and to explore implementation options. The Michigan Department of Commerce retained original project staff; consequently, the study was completed on schedule in 1982. The Michigan Department of Natural Resources assisted as technical advisers to the project.

In the first phase of the study, an assessment was conducted of the economic effects if efficient hazardous waste management options are not available to generators. The analysis encompasses the cost of on and off site management options, volume reduction through process change, and resource recovery from hazardous waste streams as well as current recovery practices. A methodology for determining factors affecting the marketability of recovered products was developed. Projections were made on current market size, and impact of financial and institutional incentives on potential market size.

Criteria were divided into three general areas: 1) industry background; 2) waste stream characterization; and, 3) those related to impact of the Resource Conservation and Recovery Act of 1976, as amended, in the region. The first criteria group ensured that industries chosen are vital to the region; the second group designated industries with significant waste management problems, and lastly, the third group addressed those industries seriously affected by implementation of RCRA in the region.

On basis of this two step approach three selections were made: 1) steel manufacturing; 2) electroplating; and, 3) paint manufacturing. Three other activities were considered but not selected: textiles, organic chemicals, and wood preserving. Other industries considered but scoring lower than the selected industries were: leather tanning, pulp and paper, electric utilities, petroleum refining, petroleum re-refining, pharmaceuticals, special machinery manufacturing, electronic components, rubber, plastic, pesticides, batteries, chemical wholesaling, drum reconditioning, agricultural services, gas and service stations, soaps and detergents, and glass.

Methodology for analyzing economic potential of recycling and resource recovery in the electroplating industry was developed. A similar analysis for solvent recovery in paint manufacturing industry was also completed. A computer model to select an optimal treatment, disposal or recovery option given varying assumptions concerning landfill costs, distance to disposal site and other parameters was the final product. Further details and conclusions can be found in Section VIII.

As part of its continuing commitment to working with State and local government, NBS has a senior staff person working with the State Solid Waste Management Board in California. The purpose of this two-year Intergovernmental Personnel Agreement is to provide an interface between perceived State measurement needs and NBS expertise (Section XI.). In addition, a great deal of cooperative work was performed with city of New York officials.

By the end of Fiscal Year 1982 most of the responsibilities mandated directly to NBS by RCRA were completed and the results transferred to interested parties. In addition to its directly mandated responsibilities, ORM has cooperated with other mission agencies within the Federal government who have other distinct responsibility in recycling and solid waste management. For example, in aid of the Department of Energy's activities under the Energy Security Act of 1980 (Public Law 96-294), the NBS Office of Recycled Materials carried out a program of research to characterize ash created by the incineration of waste, sampling of power plant ash in order to determine its potential for recycling, and developed instrumentation in cooperation with DOE to measure the amount of energy which could be produced via incineration of waste. (Sections IV-VI.) In cooperation with EPA, NBS/ORM helped in the development of methods meant to characterize whether or not a discard would be classified as hazardous. (Section VIII.) The Department of Defense was aided in characterizing materials problems associated with the incineration of waste. (Section VIII.) The ORM provided technical assistance and economic analysis to DOT and EPA in incineration at sea projects. (Section VIII.)

Section X describes a variety of evaluative activities pertaining to resource recovery which can be adapted by potential users in the public or private sectors. In the case of hazardous wastes, NBS/ORM has developed a proposed degree of hazard classification system which is easy to understand, evaluate and administer. (Section VIII.) This method is also ready for transfer to the public and private sectors. Sections XII and XIV describe NBS/ORM contributions to the institutional health of NBS. The Appendices provide specific details of work completed in FY 1982.

NBS/ORM ceased operations at the end of FY 1982 having achieved most of its objectives. The Congress concurred in this conclusion. NBS/ORM produced well over 100 publications describing its activities and results (Appendix I contains a listing); several workshops, symposia and tutorial sessions were sponsored by NBS/ORM as well.

I. INTRODUCTION

During the Congressional deliberations which led to the passage of the Resource Conservation and Recovery Act of 1976 (RCRA, Public Law 94-580), Congress perceived the need for a research and development effort which would be independent of agencies given regulatory authority under the Act. Since the lead agency was to be the Environmental Protection Agency (EPA), the Congress sought another department of the U.S. Government which would have experience and credibility in the measurement methods and techniques necessary to classify and characterize society's discards.

Congress elected to insert into the Act a separate Subtitle E assigning to the Secretary of Commerce several duties with respect to resource recovery. Specifically, the duties of the Secretary of Commerce are as follows:

- provision of guidelines for specifications for recovered materials;
- market development stimulation for these materials;
- promotion of proven technology; and
- a forum for the exchange of both technical and economic data relating to resource recovery facilities, e.g., facilities designed to recover materials and/or energy from waste.

In order to implement all of these responsibilities, the Secretary of Commerce delegated the necessary authority to accomplish the task to the National Bureau of Standards (NBS). Indeed, Section 5002 of RCRA directs "that the Secretary act through NBS in order to establish guidelines and specifications for materials which could be recovered from waste originally destined for disposal." In addition, NBS was directed to cooperate with voluntary consensus standards organizations, such as the American Society for Testing Materials (ASTM), and to work with other federal agencies in carrying out the mandates of the law.

II. FORMATION OF THE OFFICE OF RECYCLED MATERIALS

The NBS resource recovery program was formally established in November, 1976. In 1978, the program was expanded to encompass NBS responsibilities under the Energy Policy and Conservation Act of 1975 (EPCA, Public Law 94-163), section 383 of which requires NBS to determine the substantial equivalency of used and virgin oils. The work on recycled materials in response to Subtitle E of RCRA and the Recycled Oil Program were combined into the NBS Office of Recycled Materials (NBS/ORM). In late 1979, NBS added a Technical Advisory Center, which was charged with the responsibility of determining the geographic location of markets for recycled materials and with developing an economic and technical database describing resource recovery systems.

From 1976 through 1982, the NBS Office of Recycled Materials (NBS/ORM) produced 123 articles and reports pertaining to the mandates set forth under the laws to which its formation responded. A list of these publications is reproduced as Appendix I. Since this final report is a summary of NBS/ORM activities over seven years, details of the results will usually be referred back to this publications list by number. Most of the publications listed are available from NBS. In addition to the written output, over 100 oral presentations were contributed to a wide variety of audiences. Training seminars were held as were biannual symposia dealing with recycled oil. Thus, NBS/ORM was careful to insure information and technology transfer of its results to the appropriate clientele.

The NBS Office of Recycled Materials staff recognized from the outset that recovering any materials from a waste destined for disposal was possible, but purposeless unless a market could be found for the recovered material. Therefore, materials to be recovered had to be marketable at a price which made recovery economically useful.

III. THE RECYCLED OIL PROGRAM

III.1. Introduction

The recycling of oil is not a new idea but, in fact, dates back to about 1920. At that time lubricating oils had few or no additives, i.e., chemical compounds added to oils to improve lubricating characteristics such as wear, oxidation, corrosion; recycling these oils required only limited processing which included heating (to remove volatile components), settling (to separate water, dirt, and sludge), and finally centrifuging or filtering to remove most of the remaining insoluble contaminants. With this limited processing, lubricating oils could be restored essentially to original oil quality. Today, however, the types of lubricating oils in the marketplace have expanded to include a wide variety of different kinds and qualities of oils, many containing high levels of additives which can make recycling the used oils a much more difficult problem.

In 1980, new lubricating oil sales in the U.S. were estimated at 9.5×10^6 cubic meters (2.5×10^9 gallons) per year. Of this, automotive lubricants represented 4.5×10^6 cubic meters (1.2×10^9 gallons), and industrial lubricants the remainder of approximately 5×10^6 cubic meters (1.3×10^9 gallons). The industrial lubricants include hydraulic oils, quenching oils, cutting oils, metal working oils, power generation lubricants, and oils used in industrial process equipment (pumps, compressors, gears, etc.).

Of the 9.5×10^6 cubic meters of lubricating oils sold, about one-half or approximately 4.8×10^6 cubic meters of collectible used oil are generated annually in the U.S. Estimates suggest that, of the used oil which is collected each year, about 7 percent is re-refined into motor oil, 17 percent is reclaimed into industrial oil, approximately 50 percent burned for fuel or used in road oiling and dust control (often with little processing to remove contaminants), and the fate of the remaining 25 percent (approximately 1.2×10^6 cubic meters each year) is unknown.

At the present time there are a relatively small number of oil recyclers in the U.S.; estimates range between 30 and 50. Of these, only 10-20 are re-refiners, who produce a lubricating oil basestock from the used oil. The individual companies involved in oil recycling usually are small, averaging only 10-15 employees. These recyclers fall into three categories: processors (who clean up used oil for reuse as a fuel, often removing free-standing water and heavy sludge or dirt); reclaimers (who usually apply a variety of relatively simple chemical and/or physical processes to recondition the used oil for reuse as an industrial oil); and re-refiners (who employ a number of different re-refining technologies, usually with acid/clay or distillation/ finishing treatment, to remove most of the impurities and contaminants, to yield clean, quality lubricating base oils). In many cases an oil recycler may be involved with more than one of these categories, and at times with all three.

In the past, there have been a number of regulatory obstacles to increased recycling of used oils in the U.S. Two of the most significant of these were: 1) a 1965 Federal Trade Commission (FTC) trade regulation rule, and 2) the exclusionary clauses in various Federal and military specifications. The first of these, the FTC trade regulation rule, required that all recycled motor oils contain the label "...made from previously used oils...". This requirement was considered harmful to the image of re-refined oils, and was recently modified by the Used Oil Recycling Act of 1980 (P. L. 96-463). This law now removes the FTC requirement of labeling as to origin until future labeling standards mandated by the Energy Policy and Conservation Act (P. L. 94-163, Section 383) become effective i.e., NBS test procedures as provided to the FTC.

The second obstacle to increased recycling of used oils had been the specific prohibition of the use of recycled petroleum products found in a number of Federal and military specifications, e.g., burner fuels and engine oils, regardless of the quality of the recycled products. In response to requirements in the Resource Conservation and Recovery Act (P.L. 94-580), hereinafter called RCRA, and after a substantial study, the Department of Defense (DOD) has recently issued revised specifications for both burner fuel oil (Federal specification VV-F-815d) and engine oils used in administrative vehicles (passenger cars and light trucks; MIL-L-46152B). These revised DOD specifications now allow the use of recycled oils in products submitted for DOD use, provided these recycled products meet all requirements.

Technically, recycled lubricating oil products appear to be potentially suitable for all end uses with proper clean-up and additive treatment, since the basic hydrocarbon structure is not significantly altered during use. While non-technical factors such as economics and availability will determine whether some or even all potential end uses for recycled oil can be realized on a realistic basis, the national goals of energy conservation, resource conservation, pollution control, and balance of payments certainly suggest that strong efforts should be made in pursuing the goal of effective oil recycling in the U.S.

III.2. Implementation of the NBS Recycled Oil Program

The NBS Recycled Oil Program was established in 1976, in direct response to passage of the Energy Policy Conservation Act of 1975 (EPCA, Public Law 94-163; 42 U.S.C. 6201 et seq.) Section 383(c) of this law requires NBS to " ... develop test procedures for the determination of substantial equivalency of re-refined or otherwise processed used oil or blend of oil ... with new oil for a particular end use."

The goal of the Recycled Oil Program was: To provide the measurement methods and standards required for effective utilization of recycled petroleum products. This goal was pursued by:

- establishing the scientific and technical basis for characterization of recycled petroleum products;
- developing and evaluating test procedures for establishing substantial equivalency between recycled and virgin petroleum products; and
- providing technical information and support for the effective utilization of recycled petroleum products.

These goals were implemented through research and development activities both within NBS and at several outside institutions. The latest results were presented at the fourth NBS Conference on Measurements and Standards for Recycled Oil, held on September 14-16, 1982. Abstracts of papers by NBS or NBS funded research and development are included in Appendix II. Full texts of these papers will be published in the conference proceedings.

III.3. The NBS Role in Recycled Oil

Three areas of legislation provided the framework for NBS responsibilities in oil recycling. These include: 1) the National Bureau of Standards (NBS) Organic Act and its amendments; 2) the Energy Policy and Conservation Act; and 3) the Resource Conservation and Recovery Act. The model "States Used Oil Recycling Act," while not a specific article of legislation, also had an influence on the NBS responsibilities, and will be discussed briefly.

The NBS Organic Act (particularly 15 U.S.C. 272) states that NBS responsibilities include in part "... the development of methods for testing materials ... cooperation with other governmental agencies and with private organizations in the establishment of standard practices ... the preparation and distribution of standard samples ... the development of methods of chemical analysis ...." While these functions do not specifically consider the subject of recycled oil, they are consistent with the efforts required of the Recycled Oil Program as described in Sections III.(4) and III.(5).

The Energy Policy and Conservation Act (EPCA, Public Law 94-163; 42 U.S.C. 6201 et seq.) was the primary force in establishing the Recycled Oil Program at NBS in September 1976. Section 383(c) of this law requires NBS to "... develop test procedures for the determination of substantial equivalency of re-refined or otherwise processed used oil or blend of oil ... with new oil for a particular end use." The stated purposes of this legislation were: 1) to encourage the recycling of used oil; 2) to promote the use of recycled oil; 3) to reduce the consumption of new oil; and 4) to reduce the environmental hazards associated with disposal of used oils.

The Resource Conservation and Recovery Act, RCRA, 42 U.S.C. 3251), in section 6002, states that each Federal agency shall procure items with the highest percentage of recovered materials practicable. RCRA further states that any decision not to procure such recycled material must be based on one or more of the following: unavailability; unreasonable price; or failure to meet NBS performance standards (when available). This act includes recycled oils as well as other recycled materials, and when taken in combination with the EPCA, requires that NBS address the problem of performance standards for recycled oils. In addition, this law requires that exclusionary clauses in Federal and military specifications be reviewed by the appropriate Federal agency, and revised to encourage the use of recycled materials.

Finally, a model state "Used Oil Recycled Act" was sponsored by the Federal Energy Administration in 1976 and published in the Federal Register. This model act was designed to assist individual states in establishing control over used oil disposal, and clearly encourages recycling as a superior method of disposal. This model act refers directly to section 383 of EPCA for the determination of substantial equivalency for recycled petroleum products. Used oil recycling laws have been passed by at least eight states to date, and in many cases these laws are similar to the model act. Several additional states have also introduced legislation based on this model act.

The NBS role was reaffirmed by passage of the "Used Oil Recycling Act of 1980" (P. L. 96-163). This act was passed late in 1980 to alleviate the problem oil recyclers were having as a result of the FTC labeling requirements, but is to remain in effect only until the NBS test procedures become available. The U.S. Congress Committee report further states " ... the Committee believes that the work of the Bureau (of Standards) should continue .... The Committee expects the Bureau to give this work a high priority."[3]

An important reason why recycled lubricating products have not yet met with widespread consumer acceptance, both by the Federal government as well as by the public, is the lack of reliable test procedures and standards on which realistic performance criteria can be based. In the aforementioned legislation, particularly EPCA, NBS was directed to develop such test procedures and standards. These procedures will provide the basis for industry-wide performance standards and labeling requirements for recycled oil.

The resolution of this problem by NBS is particularly appropriate because it involves both the development and evaluation of measurement methods and standards, and because it requires an independent third party role for acceptance by all concerned parties (virgin oil refining industry, oil recycling industry, user industries, and government regulators). One alternative to increased recycling of petroleum oils is continued contamination of the environment and loss of a valuable resource. Recently published data indicate that, of all crude petroleum and petroleum products reaching the ocean, over 40 percent is due to used lubricating oils.

III.4. Achieving Special Objectives

The three basic objectives of the program were to:

1) Establish the scientific and technical basis for characterization of recycled petroleum products.

2) Develop and evaluate test procedures for establishing the substantial equivalency between recycled and virgin petroleum products.

3) Provide technical information and support for the effective utilization of recycled petroleum products.

The first objective deals with the research required to effectively utilize recycled lubricating oils. There is a concern among some user industries, especially the automotive industry, about the quality and batch-to-batch variability of re-refined oils. In addition, the various impurities and contaminants which can occur in a used or recycled petroleum product were of concern. A sound scientific and technical data base was crucial for the test procedures developed by NBS to be widely accepted by industry.

The second objective embodied the basic requirement for NBS action as set forth in EPCA. Realizing this objective was complicated by the current testing methods used. These tests called "engine sequence tests," call for placement of automobile/truck engines and/or special test engines onto laboratory dynamometer test stands; the actual tests are then run in sequence with different loads, speeds, temperatures, controlled blowby (gases bypassing the piston rings), etc., usually requiring special fuels. A series of controlled variables must fall within prescribed limits for the oil being investigated to have "acceptable" test results reported. For the American Petroleum Institute API SF classification, i.e., the oil quality currently necessary to maintain 1981 automobile warranties, four different engine tests must be passed. For military specifications for administrative vehicles (MIL-L-46152B, approximately equivalent to API classification SF/CC), five engine sequence tests are needed. The minimum cost of a set of these tests for a single oil is at least $30,000 for four tests, and $38,000 for five tests. Since there is no alternative set of commonly accepted test procedures or specifications for physical and chemical laboratory tests on oil basestocks or formulated oils, small re-refining companies have had a difficult time entering the lubricating oil market due to the high costs.

The third objective, to provide technical information and support for the effective utilization of recycled petroleum products, is important in accommodating recycled products for each end use. This objective includes providing technical support as required for the NBS test procedures, as well as to disseminate the NBS research and evaluation results and other technical information on used and recycled petroleum products to the industry and the consumer public. Both the EPCA and RCRA legislation contain sections which emphasize the necessity for Federal agencies to encourage the utilization of recycled products, and to educate the public with respect to the proper reuse and disposal of these products.

III.5. Program Plan and Results

The initial emphasis of the NBS Program from 1976 to 1978 concerned used oil recycled for use as fuel. This choice was made for a number of reasons:

- The primary fate of used oil at present is through burning for fuel, and is largely uncontrolled;

- There appear to be operational and environmental problems arising from uncontrolled burning of used and minimally processed recycled oils; and

- Use of waste oil as fuel could be addressed with the limited resources available at that time.

In November of 1978, the official report on Phase I of the Recycled Oil Program, "Test Procedures for Recycled Oil Used as Burner Fuel," was transmitted to the Federal Trade Commission (NBSIR 78-1453; later issued as NBS Technical Note 1130; see Publications List #7). This report contains test procedures for the operational performance of recycled oils used as burner fuel oils. Simultaneously, Phase II of the NBS Program, "Test Procedures for Recycled Oil Used as Motor Oil," was initiated.

There has been sufficient engine testing on re-refined oils to establish that: 1) a quality re-refined lubricating oil which has been formulated with a high quality additive package can be comparable to a virgin oil similarly formulated, and 2) both such oils will provide satisfactory performance in automotive service. The problem which existed was the lack of technical information and data to determine which tests are necessary and how often they should be applied in order to assure that the re-refined oil basestock is consistent in between the engine testing. The user industries have made it clear that they are concerned about the potential lack of consistency of re-refined oil products, and about the potential effects of unusual or unknown contaminants in the used oil feedstock to re-refineries. These potential problems are of particular concern when warranty questions are involved.

The most important requirement for assuring the quality of re-refined motor oil was development of a set of test procedures capable of monitoring the quality, consistency, and additive response of the oil basestock in between engine qualifications. These selected and evaluated test procedures are crucial in order to allow accommodation of the re-refined oils within the existing API-SAE-ASTM classification system. (Note: API = American Petroleum Institute; SAE = Society of Automotive Engineers; ASTM = American Society for Testing and Materials.) Development and evaluation of these tests by NBS was significantly more difficult because no such set of test procedures exists for virgin lubricating oils. Historically, virgin oil producers were instead required to control the crude source and refining technology in order to assure a constant lubricating oil basestock, particularly for the U.S. military specifications. This option was not available to oil recyclers.

The question of the consistency of re-refined oil was addressed in a cooperative ASTM/NBS/ORM Basestock Consistency Study. In this one-year study, four virgin oil producers and six re-refined oil producers submitted monthly samples of their regular production basestock for analysis by a group of 14 laboratories, including NBS (table III.1). These laboratories analyzed the coded samples using over 40 different chemical, physical, and performance tests (tables III.2-4). This database hopefully will provide the information necessary to indicate an appropriate set of test procedures to monitor re-refined basestock consistency. In addition to the consistency study, NBS/ORM evaluated the chemical and physical test procedures used on lubricating oil basestocks, and also performed research and development on bench-scale performance tests for establishing basestock additive response. Development of effective and economical test(s) for additive response was crucial to the success of our efforts.

Therefore, the strategy that NBS adopted (see fig. III.1) in providing a methodology for establishing the substantial equivalency of re-refined engine oils on a routine basis, first calls for the formulated oil quality to be determined by means of all current industry required performance tests. Further, after the quality of the formulated re-refined oil has been established, the consistency of the re-refined basestock can be monitored as a function of time through use of NBS proposed consistency tests. The concept of engine testing for quality, combined with consistency monitoring with physical, chemical, and bench tests (if needed) has been discussed previously and is included in the current military specification for administrative vehicle engine crankcase oil (MIL-L-46152 B) and is proposed for the tactical vehicle engine oil

Table III.1. Laboratories cooperating in the ASTM/NBS basestocks consistency study.

Bartlesville Energy Technology Center	Chevron, USA
National Research Council of Canada	Suntech, Inc.
Motor Oils Refining Co.	SAVANT, Inc.
Mobil Oil Corporation	Texaco
U.S. Army MERADCOM	Lubrizol
National Bureau of Standards	Gulf R&D
Shell Research/Thornton (U.K.)	Filmite

Table III.2. Physical property tests.

TEST	Method
API Gravity	ASTM D287
Aromatics	HPLC; UV
Boiling Point Range	ASTM D2287 (GC)
Brookfield Viscosities @ 0° to -40 °F	ASTM D2983
Carbon residue	ASTM D524
Color	ASTM D1500
Demulsibility	ASTM D1401
Filterability	(1)
Foam	ASTM D892
Oxidation	(1)
Pour Point	ASTM D97
Refractive Index	ASTM D1218
Sulfated Ash	ASTM D874
Viscosities @ 40 °C and 100 °C	ASTM D445
Viscosity Index	ASTM D2270

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(1) Proprietary

Table III.3. Chemical property tests.

Test	Method
Acid Number	ASTM D664
Bromine	Neutron Activation
Chlorine	Neutron Activation
Ethylene Glycol	(1)
Metals	Emission Spectrograph
Nitrogen	Chemiluminescent
Oxygen	Modified UOP
Potassium	Neutron Activation
Saponification Number	ASTM D94
Sodium	Neutron Activation
Sulfur	ASTM D1551
Water	ASTM D1744
Carbon-13 NMR Analysis	---
Polycyclic Aromatics by DMSO Extraction	IP 346
Hydrocarbon Types by TLC/FID	---
High Resolution Mass Spectrometry	(1)
Polychlorinated Biphenyls (some samples)	HPLC/GC
Chromatographic Separation of HC	ASTM D2007; ASTM D2549
Differential Infrared	---

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(1) Proprietary

Table III.4. Bench tests.

Anti-Oxidant Response	(1)
Cold Crank Simulator @ 0° to -40 °C	ASTM D2602
Differential Scanning Calorimeter	---
Ford Anti-Oxidant Capacity	---
Load Wear Index	ASTM D2783
Mini-Rotary Viscometry	ASTM D3829
RBOT	ASTM D2272
Rust Tendency	ASTM D665
Sequence III Simulator	(1)
Storage Stability	---
TOST	ASTM D943
LUBETOT	

---

(1) Proprietary

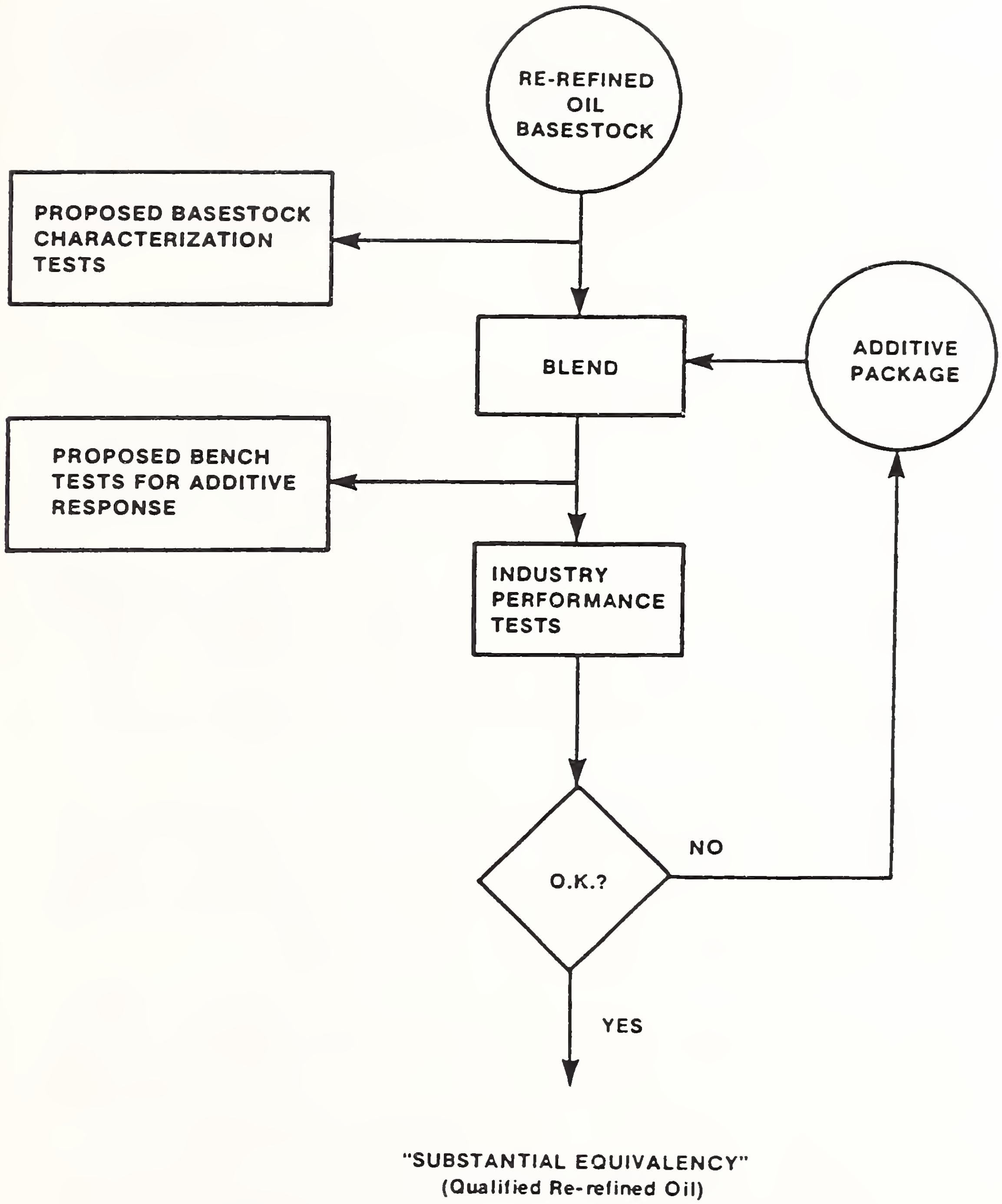
RE-REFINED OIL BASESTOCK
PROPOSED BASESTOCK CHARACTERIZATION TESTS
BLEND
ADDITIVE PACKAGE
PROPOSED BENCH TESTS FOR ADDITIVE RESPONSE
INDUSTRY PERFORMANCE TESTS
O.K.?
NO
YES
"SUBSTANTIAL EQUIVALENCY"
(Qualified Re-refined Oil)

Figure III.1. Proposed Re-refined Engine Oil Qualification Procedure.

specification (MIL-L-2104 D). This methodology is discussed in more detail in Section III.(6) of this report.

III.6. Proposed Test Procedures for "Substantial Equivalency

At the September, 1982 recycled oil conference, NBS proposed a re-refined oil testing system meant to be capable of establishing the "substantial equivalency" of re-refined to virgin engine oil. This system is composed of two parts, one being the proposed re-refined oil qualification procedure and two being the proposed re-refined oil consistency monitoring procedure. The latter can be used to monitor the re-refined oil, once quality has been established through appropriate engine testing.

III.6.a. Performance Tests (Qualification Procedures)

The performance tests proposed for use with re-refined oil are identical to those necessary for the various API Engine Service Classifications and the military specifications for engine oil, and are listed in table III.5. The primary performance criteria for these tests are also found in SAE J-183 and SAE J-304, ASTM STP 315, ASTM STP 509 and Federal Test Method STD #79.

Re-refined oils to be engine tested and monitored for consistency under the proposed system described here usually will have been fully formulated with an engine oil crankcase additive package, and will have been found to provide acceptable performance with that specific additive package and at that specific treat level. The actual engine testing may be obtained through various means, e.g. purchased at commercial test facilities; run by additive supplier as a customer service.

Concurrent with the engine testing, in order to implement the proposed system discussed here, a complete set of base oil characterization tests (as described in III.(6)b) must be made of that same re-refined base oil (and formulated oil, to be used with the bench test for additive response) in order to determine the baseline data required to monitor the basestock consistency.

The proposed system of tests should be applicable to as many categories as possible. They may apply to the CD category as well, but that has not been evaluated. Thus, the API Service categories include, in addition to the SF category, oils classified as SA, SB, SC, SD, SE, CA, CB, and CC. These oils are described in table 5 along with their respective current engine test requirements as taken from SAE recommended practice J-183. Where such categories are accepted by the lubricant industry, it could be expected that re-refined oil would need to meet the same testing requirements as the virgin engine crankcase oils. However, for some of the API Service categories, the engine tests are obsolete or no engine tests are required. While these oils may represent only about 20 percent of the engine oil market, nevertheless some oils in these categories are actively produced and marketed, and are at least

Table III.5. General requirements for API engine service categories and U.S. military specifications.

API Engine Service	Use	Current Engine Test Requirements[a]
SA[b]	Utility Gasoline or Diesel Engines	none
SB[b]	Minimum Duty Gasoline Engines	Sequence IV (obsolete); L-38
SC	1964-1967-Gasoline Engine Warranty Service	Sequences IIA, IIIA, IV, V and L-1 (all obsolete); L-38
SD	1968-1970 (some 1971) Gasoline Engine Warranty Service	Sequences IIB, IIIB, IV, VB, L-1 or 1-H, Falcon (all obsolete); L-38
SE	1971-1979 Gasoline Engine Warranty Service	Sequences IID, IIID, VD; L-38
SF	1980 and newer-Gasoline Engine Warranty Service	Sequences IID, IIID, VD; yc L-38
CA	Light Duty Diesel Engine Service	L-1 (obsolete); L-38
CB	Moderate Duty Diesel Engine Service	L-1 (obsolete); L-38
CC	Moderate Duty Diesel and Gasoline Engine Service; (includes some current automotive requirements	LTD (obsolete)[d]; L-38, IID, 1-H2
CD	Severe Duty Diesel Engine Service	1-G2, L-38
MIL-L-46152B[e]	Military specification for crankcase lubricants for administrative vehicles (approximately equivalent to SF/CC lubricant)	IID, IIID, VD, L-38, 1-H2

Table III.5 (cont'd)

API Engine Service	Use	Current Engine Test Requirements[a]
MIL-L-2104Cyd	Military specification for crankcase lubricants for heavy duty diesel engines (approximately equivalent to SC/CD lubricant)	IID, IIID, VD, L-38, 1-G2

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[a] Obtained from the 1981 SAE Handbook.

[b] Old Engine Service categories; should not be used in any engine unless specifically recommended by manufacturer.

[c] Sequence Tests for SF have different performance criteria then for the SE categories.

[d] While this test is listed as obsolete in J-183 (1981 SAE Handbook), ASTM has provided special criteria to allow it to be used for evaluating CC oils, if required.

[e] Not an API Service categories, but a separate military specification.

tolerated by the lubricant and automotive industries. For example, in the API Service category SA, no engine tests or other tests are currently required for either virgin or re-refined oils. Therefore, in the system proposed in figure 1 as well as in current industry requirements, a re-refined oil would meet the requirements for substantial equivalency to an SA virgin oil with no testing. This unfortunate situation would exist until such time as testing requirements are instituted by the API for their Service category SA.

III.6.b. Provisional tests for re-refined basestock consistency

For the past four years, the NBS Recycled Oil Program has carried out an extensive research effort on lubricating base oil characterization and testing. That research culminated in a series of publications detailing the evaluation of existing test procedures for use with re-refined oils, the development of new tests where it was felt that existing tests were not adequate, and the determination of which characteristics of re-refined oil should be tested in order to monitor consistency in a re-refined oil already shown to be capable of producing a high quality crankcase oil.

These publications include many of the papers presented at the 1982 NBS Recycled Oil Conference, as well as a number of additional papers already published or in the process of being presented and published (Publications List #'s 16-37). In particular, the paper entitled, "Re-refined Base Oil Characterization and Consistency Monitoring," summarizes the data and findings of this research effort (Publ. List #106). Subjects covered in this paper include: lubricating base oil quality; re-refined base oil characterization; comparison between re-refined and virgin base oils; physical properties; chemical properties; hydrocarbon structures; effect of viscosity grades on properties; contaminant isolation and analysis; bench performance characterization of oxidation and wear; base oil composition-oxidation performance correlation; and consistency of re-refined base oils.

The data and results presented in these publications are far too extensive to discuss in detail here, but in summary, the results thus far show that some re-refined base oils, when compared to a set of typical medium to low sulfur crude derived virgin base oils in approximately the same viscosity grades, showed measurable and real differences in some characteristics, e.g, oxyacids, VI improvers, chlorine, additive/wear metals and in some test results, e.g., total acid number (TAN), saponification number (SAP. NO.). Since the effect of all such variations on performance is still not well understood, a two level testing system is being proposed for the measurement of re-refined oil consistency as shown in figure III.2. Initially, the re-refined base oil undergoing engine testing would be characterized using the following physical/chemical tests (table III.6): API gravity, viscosity index, pour point, flash point, sulfated ash, TAN, SAP NO., clay-gel chromatography, chlorine, boiling point distribution by gas chromatography, infrared spectroscopy, and metals analysis, e.g., by atomic absorption (AA) or emission spectroscopy (ES). Further, after formulation with the

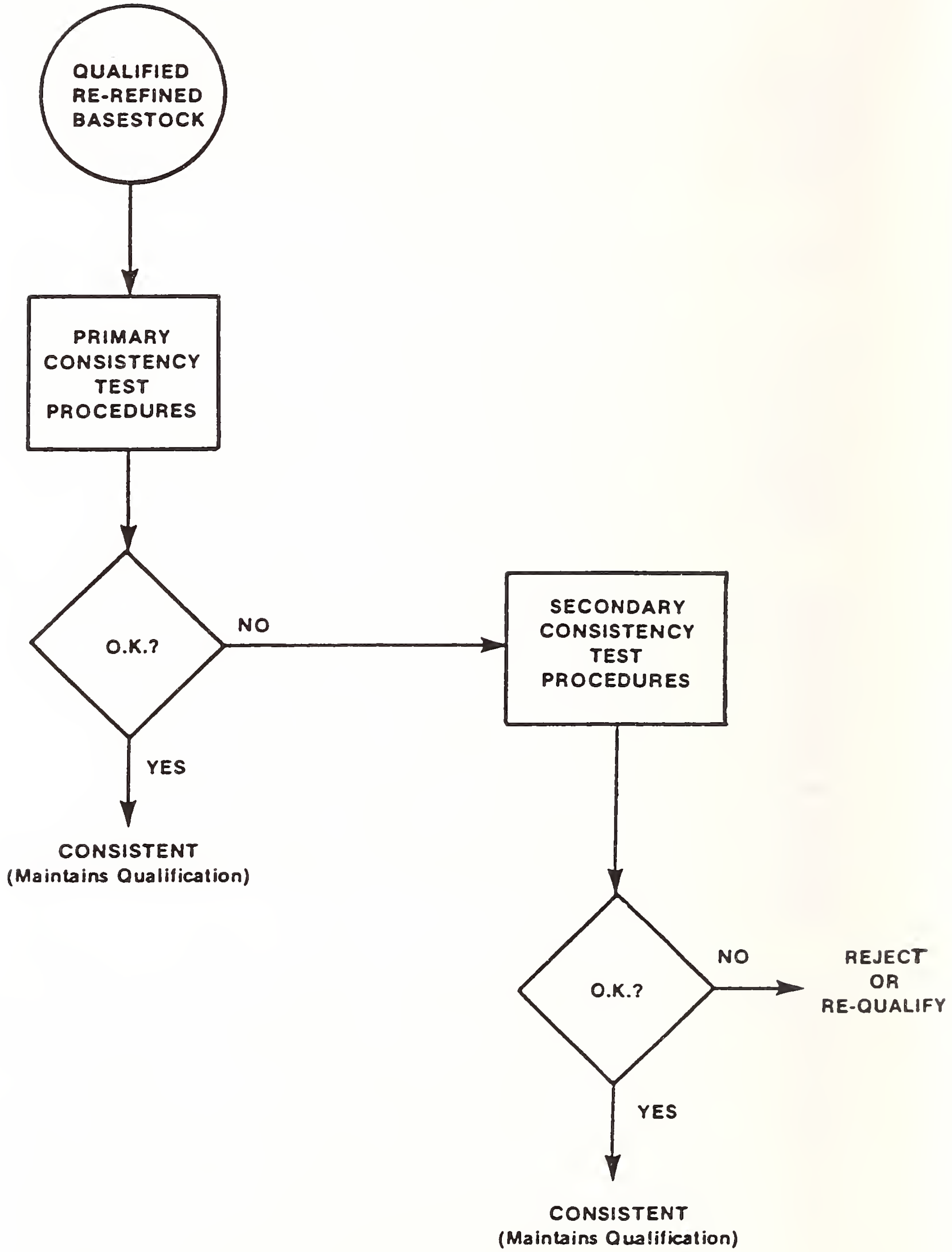
QUALIFIED
RE-REFINED
BASESTOCK
PRIMARY
CONSISTENCY
TEST
PROCEDURES
O.K.?
NO
SECONDARY
CONSISTENCY
TEST
PROCEDURES
YES
CONSISTENT
(Maintains Qualification)
O.K.?
NO
REJECT
OR
RE-QUALIFY
YES
CONSISTENT
(Maintains Qualification)

Figure III.2. Proposed Re-refined Engine Oil Consistency Monitoring Procedure.

Table III.6. Proposed provisional test procedures.

Characterization Tests	Reference	Provisional Consistency Tests Primary	Secondary
API Gravity (Density)	ASTM D287	X	
Viscosity Index	ASTM D2270	X	
Pour Point	ASTM D97	X	
Flash Point	ASTM D92	X	
Sulfated Ash	ASTM D874(M)ya	X	
Total Acid No. (TAN)	ASTM D664	X	
Saponification No. (SAP. NO)	ASTM D94	X	
Clay-gel Chromatography	ASTM D2007		X
Chlorine Analysis	Publ. List #		X
Boiling Point Dist. by GC	ASTM D2887		X
Infrared Spectroscopy	b		X
Metals Analysis	AA, ES		X
Thin Film Oxygen Uptake Test (TFOUT)	Publ. List #	X	
Four ball Step Loading Seizure Test (SLST)	Publ. List #		
Bearing Corrosion Test	c		X

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[a] As modified; see Publ. List #36

[b] See equipment manufacturers literature for determination of relative carbonyl absorption.

[c] NBS research on this test is not complete; Fed. Test. Method Std. 79 appears to provide a test with appropriate correlation to the L-38 engine test.

additive package, the following bench tests would be made: NBS thin film oxygen uptake test (TFOUT), NBS four-ball step loading seizure test (SLST), and a bearing corrosion test.

The resultant data would then be used to establish a set of limits for each of the above tests. The actual procedure to be used in developing these test limits probably should be developed by joint government/ industry/ASTM groups. Once established, subsequent production samples of re-refined oils can be tested without additives in seven tests (table III.7): API gravity, viscosity index, pour point, flash point, sulfated ash, TAN and SAP. NO. If the base oil meets the preset limits, the oil is then blended with the same additive package used to pass the engine tests, and tested in the TFOUT test. If the TFOUT test result meets the preset limit, the re-refined base oil could then be declared consistent.

However, if the re-refined base oil fails to meet the limit(s) in one or more parameters, then one or more additional tests are indicated. The additional ("secondary") tests needed to further evaluate the characteristics for each of the primary tests are listed in table III.7. Results from the additional tests should be compared with the baseline characterization tests results of the initial sample. If the results deviate significantly from the preset limit(s), the sample under test should be rejected as inconsistent. The overall characterization scheme is shown in figure III.1 and table III.6, and the consistency monitoring scheme in figure III.2 and table III.7.

The success of this proposed consistency monitoring system relies heavily on the reasonableness and technical soundness of the limits derived from the initial characterization testing.

III.7. Discussion of a Potential Test Procedure Verification Effort

The engine oil testing system as proposed by NBS hopefully will be capable of providing an adequate methodology for establishing and monitoring the substantial equivalency of re-refined lubricating oil basestocks to be used as engine crankcase oil. Performance tests, including particularly the engine tests, Part One of the testing system, are fully accepted throughout the lubricant industry as indicators of engine oil quality. Part Two of the testing system, the set of provisional physical/chemical/additive response tests to monitor consistency in the refined oil basestock, provides a mechanism for possible quality control.

With respect to the set of provisional tests for consistency, a period of verification of these tests would appear to be necessary before full implementation should be attempted. That is, a controlled

Table III.7. Provisional tests for consistency monitoring

Primary Test	Secondary Test (if the Oil Fails to Meet the Limits of the Primary Test
API (Gravity)[a]	ASTM D-2007 (saturates)
Viscosity index	ASTM D-2007 (polars)
Pour point	ASTM D-2007 (aromatics and saturates)
Flash point	Boiling Point Distribution by GC
Sulfated ash	Metals analysis by AA/ES
TAN	Chlorine + bearing corrosion test + 4 ball wear test (SLST)
Saponification number	Chlorine + carbonyl by IR + 4 ball wear test (SLST)
NBS TFOUT test	Reject

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[a] Equivalent to density/specific gravity.

application of these tests to re-refined oils over a period of time is needed to insure that they are completely capable of fulfilling the requirements of consistency monitoring. Upon successful completion of such a verification process, the provisional re-refined engine oil testing system as described here, should be an acceptable procedure for establishing that a re-refined engine oil product is substantially equivalent to a virgin engine oil.

At present, who will ultimately complete the verification effort described above is not clear. Certainly, ASTM and/or SAE would have the necessary technical expertise, but it is not obvious at this time whether sufficient motivation exists in these organizations to move strongly into fulfilling these verification needs. Several industry associations have made an effort to convince the Congress to provide additional funding for NBS to continue to characterize recycled oil in FY 1983. If funds are provided by Congress, NBS has agreed to continue to study recycled oil, even though the NBS/ORM officially ceased to exist as of September 30, 1982.

If funded, the primary effort for NBS in FY 1983 will be to initiate the requisite verification process. Another important effort will be to initiate discussions on the proposed set of tests with various industrial, technical and governmental organizations to obtain their views on these tests. Under normal circumstances, these discussions would have occurred prior to presentation of the proposed tests at the NBS Recycled Oil Conference (September 14-16, 1982). But, due to the then imminent termination of the Program, all available resources were concentrated on completing the research necessary for presentation of the test procedure evaluation and development; this work was only completed immediately prior to the NBS Conference.

III.8. Summary of Achievements

In the six years of its existence, the Recycled Oil Program of NBS/ORM has effectively responded to the legislative mandates of the Energy Policy and Conservation Act. During this time, the Recycled Oil Program of NBS/ORM and the associated Tribochemistry Group (headed by Dr. Stephen M. Hsu) in the NBS Center for Materials Science, have established a lubricating oil research center that has rapidly advanced to the forefront of lubrication research in the U.S. The efforts of this group have culminated in work that is likely to substantially affect both re-refined and virgin lubricating oil standards and testing in the future. In addition, this team has cooperated with many technical and trade organizations as well as private companies and government agencies. Wide dissemination of results and information to all interested parties has been achieved.

Major highlights of these NBS/ORM efforts include the following:

1) Organized and held four major Conferences on Measurements and Standards for Recycled Oil (1976, 1977, 1979, 1982).

The widely disseminated Proceedings from these Conferences have included virtually all of the significant activities in oil recycling during this period.

2) Was instrumental in creating the new ASTM Technical Division P, on Recycled Petroleum Products and Lubricants. This Technical Division now has over 100 active members.

3) Established outstanding laboratory facilities, equipment, and sample storage/blending facilities in support of the state-of-the-art research activities in the Tribochemistry Group.

4) Obtained senior staff member from a major additive company to head research efforts; obtained and trained non-lubrication scientists into cohesive, productive lubrication research group. Also obtained two Industrial Research Associates during this period.

5) Completed an extensive ASTM/NBS re-refined oil basestock consistency study. In this study, monthly oil samples from six re-refiners and four virgin oils refiners, after subsampling and coding by NBS, were analyzed for 47 characteristics by 14 laboratories in three countries. These results are the most extensive ever compiled on a representative set of lubricating oils, and provided the data necessary for the selection of the proposed NBS tests for re-refined oil basestock consistency.

6) Provided cooperative efforts in support of four important non-NBS recycled oil programs:

   - U.S. Army MERADCOM's development of several Federal and Military Specifications which now allow the use of re-refined or recycled oil.

   - Environment/Canada's fleet test evaluation of re-refined oil in Royal Canadian Mounted Police vehicles.

   - Department of Energy's continuing study on the fate and effects of contaminants in used oil feedstocks provided to re-refiners and recyclers.

   - Conducted PCB analysis round robin in support of ASTM efforts to develop an analytical procedure for PCBs in used oils.

An independent confirmation of the effectiveness and quality of the above efforts took place in October, 1982, at the annual Society for Automotive Engineers Fuel and Lubricants Meeting in Toronto. At a special symposium on base oils for automotive lubricants, NBS lubrication research scientists associated with the Recycled Oil Program provided three out of the total of eight invited papers.

In conclusion, the Recycled Oil Program of NBS/ORM provided test procedures for recycled oil used as burner fuel [NBS Technical Note 1130 (1980)], and proposed a system for the effective utilization of re-refined oil as automotive engine oil, including a proposed set of test procedures for re-refined basestock consistency. These test procedures are expected to be effective in providing the technical foundation for the efficient utilization of recycled oil products. Some 49 papers and reports have been published (Publ. List #'s 1-38 and 99-109).

IV. RECYCLED MATERIALS PROGRAM IN RESPONSE TO RCRA

IV.1. Mandates and General Approach

Specific legal mandates assigned to the Secretary of Commerce and delegated ultimately to the NBS Office of Recycled Materials are to be found in the Resource Conservation and Recovery Act of 1976 (P. L. 94-580), as amended (P. L. 96-482). (The following is reproduced directly from P. L. 94-580)

"Subtitle E -- Duties of the Secretary of Commerce in Resource Recovery

"FUNCTIONS

"SEC. 5001. The Secretary of Commerce shall encourage greater commercialization of proven resource recovery technology by providing --

"(1) accurate specifications for recovered materials;
"(2) stimulation of development of markets for recovered materials;
"(3) promotion of proven technology; and
"(4) a forum for the exchange of technical and economic data relating to resource recovery facilities.

"DEVELOPMENT OF SPECIFICATIONS FOR SECONDARY MATERIALS

"SEC. 5002. The Secretary of Commerce, acting through the National Bureau of Standards, and in conjunction with national standards-setting organizations in resource recovery, shall, after public hearings, and not later than two years after the date of the enactment of this Act, publish guidelines for the development of specifications for the classification of materials recovered from waste which were destined for disposal. The specifications shall pertain to the physical and chemical properties and characteristics of such materials with regard to their use in replacing virgin materials in various industrial, commercial, and governmental uses. In establishing such guidelines the Secretary shall also, to the extent feasible, provide such information as may be necessary to assist Federal agencies with procurement of items containing recovered materials. The Secretary shall continue to cooperate with national standards-setting organizations, as may be necessary, to encourage the publication, promulgation and updating of standards for recovered materials and for the use of recovered materials in various industrial, commercial, and governmental uses.

"DEVELOPMENT OF MARKETS FOR RECOVERED MATERIALS

"SEC. 5003. The Secretary of Commerce shall within two years after the enactment of this Act take such actions as may be necessary to --

"(1) identify the geographical location of existing or potential markets for recovered materials;

"(2) identify the economic and technical barriers to the use of recovered materials; and

"(3) encourage the development of new uses for recovered materials.

"TECHNOLOGY PROMOTION

"SEC. 5004. The Secretary of Commerce is authorized to evaluate the commercial feasibility of resource recovery facilities and to publish the results of such evaluation, and to develop a data base for purposes of assisting persons in choosing such a system."

Other than oil, NBS involvement with recycled materials spans several decades. However, the program described here dates from 1973 when data concerning reactions from incineration of municipal solid waste were obtained by the Physical Chemistry Division. In 1976, the Congress via the Resource Conservation Recovery Act (RCRA), assigned DOC and NBS direct responsibilities for research concerning recycling. The Office of Recycled Materials within NBS was the Departmental focal point for fulfilling these legal mandates. The goals and objectives of the RCRA program were as follows:

IV.1.a. Goal

To improve the Nation's productivity and innovation by providing a framework for fostering the advances required to optimize the mix of economic and environmental factors associated with the disposal and subsequent recovery and/or reuse of resources contained in municipal, industrial, commercial and hazardous solid wastes.

IV.1.b. Objectives

1) To develop methodologies for the economic assessment of current and potential technologies, market potentials, and institutional barriers relative to resource conservation and recovery, and to assist public and private sectors to fully utilize both the methodologies and information derived therefrom; 2) to evaluate current and innovative technologies for the conservation of materials, as well as the recovery, reuse, and recycling of waste materials from all potential sources including industrial processes; 3) to provide for the economic retention and development of businesses and industries through mitigation of the impact of Federal regulatory policies, particularly environmental actions, and by utilizing the potential of new business opportunities and growth.

The NBS efforts were divided into three main categories:

1. Direct laboratory-based research aimed at achieving the goals of RCRA;

2. Examination of governmental policies with respect to procurement of products containing recovered materials; and

3. Identification and assessment of the need for uniform physical and chemical measurements which derive from laws, regulations and policies at the state and local level.

IV.1.c. Technical Advisory Center

A Technical Advisory Center (TAC) was established in late 1979 to provide a framework for fostering the advances required to optimize both economic and environmental factors associated with recovery and/or reuse of resources contained in solid wastes. The TAC accomplished these goals by developing methodologies for the economic assessment of current and potential technologies and market potentials, as well as by identifying institutional barriers to resource conservation and recovery; by assisting the public and private sectors to utilize the methodologies and information; and, by identifying the potential for new business opportunities and growth. TAC's primary function was to assure implementation of RCRA responsibilities of the Department, which were (i) encouragement of the commercialization of proven technology; (ii) stimulation of the development of markets for recovered materials, and (iii) evaluation of the commercial feasibility of resource recovery facilities as well as the development of an information base to assist communities and other entities in selection of a recovery system.

IV.1.d. NBS/ORM Participation with the Waste Management Policy of the Organization for Economic Cooperation and Development

The Waste Management Policy Group (WMPG) of the OECD has eighteen active member nations representing virtually the entire industrialized portion of the non-communist block. The mandate of the WMPG is to:

- Identify and develop the essential elements of an overall waste management policy to meet both economic and environmental objectives.

- Focus special emphasis on such issues as waste reduction, encouragement of recycling and recovery of resources from waste, hazardous waste challenges, and the promotion of energy recovery from waste.

Since the mandates of Subtitle E of RCRA and the WMPG are quite similar, participation in the endeavors of the WMPG provided NBS/ORM a voice in international waste management policy. Such activity enabled DoC to be aware of and to benefit from detailed knowledge of international practices and experience. The Chief, NBS/ORM served as a member of the U.S. Delegation to WMPG from 1979 through 1982.

IV.2. General Statement of the Challenges Posed by the Need To Deal with Municipal Waste

There is generated in the United States about 150 million tons of post-consumer solid waste per year and well over 50 million tons (dry basis) of potentially hazardous wastes, the disposal of which involves methods that often preclude any future value to the national economy and which indeed may be hazardous to the human environment.

Table IV.1 taken from the National Recycling Directory (compiled under the aegis of NBS/ORM, Publ. List #60) lists some uses for a variety of recovered materials. In cases where paper and other wastes are mixed, energy can be reclaimed by burning such materials. Chemical wastes, in a number of instances, can be recovered with conventional technology and reused. This process can reduce the burden of disposing of these potentially hazardous materials. Many of the materials and substances found in waste destined for disposal can be reclaimed in some potentially useful form. The generic term for such activity is "resource recovery."

There are various methods of resource recovery that can be employed, from source separation to mass burning, to the use of more advanced technology that can further enhance the value of the recovered commodities. No matter which method is selected, however, it must be designed to provide recovered commodities in an acceptable form and at acceptable prices to achieve full marketability. Therefore, dealing with solid waste represents one part of a larger waste management strategy involving environmental considerations, health and safety aspects, transportation factors, labor and other institutional factors. The foundation underlying any such strategy is the "bottom line," i.e., economic efficiency.

In dealing with newer concepts and technologies for recovery and reuse of resources destined for waste, several parties must of necessity be involved. The parties involved in planning, and implementing, resource recovery and reuse of materials from solid wastes include:

1) The communities generating solid waste who are facing solid waste management problems.

2) The state and local governmental bodies who have the responsibility of ensuring that solid waste disposal practices are environmentally sound.

3) The recycling and basic industries who are the potential customers and users of materials recovered from solid waste.

4) The potential users of energy recovered from solid waste.

5) The resource recovery industries that are the sources of recovery technology, equipment and resource recovery plant construction capabilities.

Table IV.1. Uses of Recovered Materials.

	RECOVERED MATERIALS USED	PRODUCTS
FERROUS METALS	tin and bi-metal cans, tin-free steel cans, iron scrap, steel scrap, old automobiles	cans, tin ingot, steel tubular goods, steel castings, iron and steel fabrication, iron castings, manhole covers, copper precipitation
GLASS	bottles, jars, cullet	brick, terazzo, foamed glass products, glass wool insulation, glassphalt, abrasives, reflective material for paint, glass containers, glass polymer composites
NON-FERROUS METALS		
Aluminum:	cans, foil trays and pie cans, insulated aluminum wire, aluminum scrap	secondary aluminum ingot, sheets for can manufacturers, cans, aluminum shot, doors, windows, extrusions
Other:	lead batteries, lead scrap and alloys nickel alloys copper wire, brass and bronze scrap zinc scrap	pure lead and lead alloys, fishing sinkers and net weights, solder recovered nickel recovered copper and brass zinc dust, metal and anodes
PAPER	corrugated, newspaper, grocery bag wastes, draft, envelope cuttings, books and magazines, computer print out, white ledger, tab cards, mixed waste paper	insulation, tissue, newsprint, linerboard, corrugating medium, boxboard, chipboard, construction paper and board, protective packaging, paper bags, nursery pots, roofing felt, printing and writing paper, stationery
PLASTIC	low density polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyethylene containers, thermoplastic scraps, scrap resins and powders	low density polyethylene film, reprocessed or reclaimed thermoplastic reslin, polyethylene and polypropylene, drainage products, toys, boats, artificial flowers
RUBBER	tire inner tubes, used tires, synthetic rubber scrap	asphalt additives, jetty and seawall coating, lining sheets, highway guard rails and shock absorbers, rubber mats, carpet padding and lining, floor coverings, rubber conveyor and power transmission belts, automotive hoses, a variety of molded parts and extrusions, athletic court surfacing, new tires, rubber footwear, reprocessed synthetic rubber
TEXTILES	used clothing, garmet manufacturing waste, textile mill by-products, cordage and twine, yarn wastes	wiping rags, fabric stock for recycling, felt goods, padding and unholstery filling, floor maps, industrial mats, fine writing paper

6) The transportation industry that plays a most important role in collecting and delivering solid waste as well as transporting the recovered products to their markets.

7) The innovative technology firms who will provide improvements to recovery processes, improvements to the products recovered and the development of new uses or recovered products.

8) The financial community who will be called on to provide the capital for the construction of resource recovery facilities.

9) The Federal Government in its responsibilities under RCRA.

Experience has shown that unless a partnership can be arranged between all of these parties, resource recovery options are almost certain to be discarded, delayed, or implemented inappropriately. Because local or state governmental bodies are responsible for solid waste management, in most instances, these bodies also are responsible for establishing the optimum partnership between all of the parties involved.

A concept which is emerging and which should aid in establishing the necessary partnership is that recovery of usable materials from the waste stream is unique in the field of environmental control in that it can be combined with or act as a spur to an area's economic development. Resource recovery provides a new source of industrial feedstocks. As a result of these new feedstocks becoming available, new industrial operations often can be encouraged to locate in the vicinity of the recovery operations. Alternatively, existing companies may expand their operations. In addition, because resource recovery is one of the few environmentally acceptable methods for managing municipal solid wastes and industrial residues, it allows increased economic activity without the usual attendant environmental effects. Thus, resource recovery offers an opportunity to not only attack disposal of solid wastes but to address other issues simultaneously since proper development and management of resource recovery programs can provide significant economic development benefits to host communities and/or regions.

Economic development can be best stimulated by resource recovery programs when there are multiple opportunities for marketing the materials and energy so desired. But ready markets do not often exist for recovered components from mixed municipal solid waste; in response, there have been efforts to develop market strategies and product specifications. Whether from mixed waste processing facilities or from source separation, there is the common requisite that a particular material be able to compete -- in quality and price -- with the material to be substituted for. In this sense, selling recovered materials and fuels is not different from selling virgin materials and fuels.

In the challenge to market recovered products, there are two important elements: 1) the ability to consistently separate targetted materials in salable form, and 2) the availability of customers for the recovered materials. In planning for a recovery-from-waste facility, it is that second element that determines the technology to be selected, and markets must be identified for each material as a first step in an economic analysis in the total context of the solid waste-economic development strategy for a town, city, state or region. In every case, however, recovery technology must be matched to existing markets or new technology must be developed to create increased use and therefore market demand for the recovered resources.

The first step in a general conceptual approach toward evaluating resource recovery in economic terms is to carry out market surveys in terms of what recoverables might sell and in what quantities as a function of time. In addition, the quality of the recoverables must be ascertained via specifications. Specifications can be defined as designations of the particulars or form and/or composition of products and materials; they are a method of communicating an exact description of the material. Specifications are used in most forms of commerce, including the production and sale of products recovered from mixed municipal solid waste. Specifications form the basis for acceptance or rejection of the products or materials, and may be used to determine price as well. Clearly, needs for new materials as feedstocks for industrial processes, energy production, soil conditioners, and others vary greatly from one area of the U.S. to another as do waste streams themselves.

Once a market survey indicates that resource recovery may be economically and/or environmentally beneficial, commitments from prospective purchasers of recoverables must be sought before final technological details can be developed. A major step in this direction has been the development of realistic, letters of intent to purchase. Such an instrument is negotiated between the resource recovery planner and the potential purchaser of recovered materials. The letter of intent sets fundamental terms and conditions of an advance commitment such as the length of commitment, quantity of material, quality (specifications), delivery schedule, termination and price. It provides the necessary financial underpinning to the resource recovery project and is the precursor to the buyers purchase orders.

At this point, the risks associated with potential demand as a function of time for the recoverables can be assessed. If commitments for all recoverables exist, a technology which will obtain those recoverables at an acceptable cost is needed. If such commitments are incomplete, then new demand for the recoverables needs to be stimulated if possible. In either case, innovative technology at an acceptable cost may be required.

IV.3. Guidelines for Specifications for Recovered Materials (Section 5002 of RCRA)

There are three main sub-areas of responsibility set forth in Section 5002. Each of these was dealt with by the Management and Staff of the Office of Recycled Materials.

IV.3.a. Provision of Guidelines for the Development of Specifications for the Classification of Materials Recovered from Waste. Physical, Chemical and Other Characteristics of Such Materials Were to be Determined

From the inception of ORM in 1976, the requirement for "provision of guidelines for the development of specifications" was interpreted to mean that the major recyclable constituents of waste destined for disposal needed to be characterized as to various material properties in order to state what parameters needed to be taken into account in a set of specifications. No attempt was to be made to set quantitative limits for individual specifications. In this, ORM was adhering to the letter of P. L. 94-580 and to the spirit of the following quotation from The Life and Work of Charles Benjamin Dudley, STP 1, American Society for Testing and Materials (P. 127):

> "The special fault which characterizes many specifications is the attempt on the part of the one who draws the specification to make it a place to show how much he knows. We have seen specifications which were apparently drawn with no other thought in mind than to embody all the knowledge the writer had on the subject. No discussion is needed on this point. The folly of it is apparent to all.
>
> "Another fault is putting too many restrictions into the specification. According to our views, the fewer possible restrictions that a specification can contain, and at the same time afford the necessary protection in regard to the quality of the materials, the better the specification is. In some of our specifications we have only one test; in others, perhaps half a dozen; the effort, however, being always to have the minimum number which will yield the product that is required.
>
> "A third fault in specifications is in making the limits too severe. Some writers who draw specifications apparently put themselves in a position of absolute antagonism to those who are to make the material, and seem to have as a permanent thought in their minds to tie them down to the extreme limit. The maximum that a single test piece shows, the minimum of an objectionable constituent that may be obtained by analysis, the extreme point in elongation that by chance some good and exceptional sample gives, are made to represent the total output of the works. It is, perhaps, needless to say that such extreme figures are the worst possible mistake in making specifications."

While many waste streams, e.g., agriculture, nuclear, could have been examined, ORM chose to deal with municipal solid waste, certain large volume industrial wastes, ash, certain potentially hazardous wastes and, as previously described, used oil.

IV.3.a.1. Municipal solid waste (MSW)

Post-consumer MSW consists of about 80 percent organic material, 1 percent aluminum, 8 percent ferrous materials and 11 percent glass by weight. These are approximate national averages. The organic fraction includes potentially recyclable fibers such as newsprint (8-12 percent by weight). Certain items - glass, metal, newsprint - can be separated at the point of discard to provide a fairly uniform feedstock material for recycling. Note that "complete" source separation would account for 20 to 30 percent by weight of MSW. The remainder would be largely the putrescible organic fraction. Mixed MSW is simply MSW from which little or no separation has been previously effected.

IV.3.a.1.1.a. The aluminum fraction

Recovery of aluminum is possible by mechanical separation from mixed MSW. The generic implement used to obtain separation of Al from other constituents is an eddy current device. This device can be placed in the mechanical sorting train to examine the heavy (primarily inorganic material) MSW fraction after ferrous materials have been magnetically separated. Eddy current devices recover about 65 to 90 percent of the Al which passes through them. Some aluminum loss is experienced during other prior mechanical sorting of the mixed MSW.

Since the aluminum content of the waste is low and unevenly distributed nationally, a careful survey is needed by proponents of mechanical sorting prior to investing in recovery of Al from mixed MSW:

1) Determine amount of Al in the waste which would come to the sorting facility

2) Determine chemical composition of Al based mixture which can be sorted;

3) Determine if a market exists for this composition.

ASTM, with a contribution from NBS/ORM, has developed a standard specification for municipal aluminum scrap (MAS) designated ASTM-E753 including physical and chemical specifications for Al scrap. Clearly, the prospective seller of Al material separated from mixed MSW must be able to demonstrate that the output material meets required specifications for each batch to be shipped. Thus, fairly constant and elaborate quality control procedures need to be planned and implemented. ASTM-E753 represents the current guidelines for specification of MAS.

Consider a mechanical sorting operation in which the operator estimates an input of 10 tons daily of Al material in a total input of 1000 tons per day of mixed MSW. Approximately 6.5 tons of saleable Al product might be obtained daily or 1950 tons annually. With current capital costs for the eddy current devices ($2 million) current interest rates, and operating and maintenance costs and a selling price of about $450 per ton for the mixed material, the maximum net income to the operator is estimated as about $350,000 annually or about $1.17 per input ton of mixed MSW. If certain shipments are rejected as being out of specification, these modest gains could become losses.

Al in the MSW stream often comes from beverage containers. Since source separated Al cans can be used directly to prepare additional can bodies at a great savings of energy and raw material, can manufacturers prefer this recycling route. Hence, these manufacturers often survey a given area as a basis for an investment decision to install major can return facilities and programs. If enough Al cans are likely to be obtained, then the manufacturers will buy the product, shred it and ship to appropriate smelters. Manufacturers of Al beverage cans currently claim that 50 percent of all Al used for this purpose is recycled.

The net result is that virtually no one is willing to risk placing eddy current sorters in a plant meant to deal with mixed MSW since the projected financial gains could easily become losses and since much of the Al available as beverage cans might never arrive at the plant. Therefore, under present conditions, an "effective specification" for Al which might appear in MSW is that of the typical Al beverage can. There is a ready market for all such cans throughout the U.S.

IV.3.a.1.b. The ferrous fraction

Ferrous metal in mixed MSW usually results from discarded cans consisting of either tin free steel or tin plate. Often steel beverage cans having aluminum "flip-tops" are found as well. As early as 1975, ASTM Committee E-38 on Resource Recovery identified several potential uses for steel cans:[1]

- o substitute for iron ore as a charge to blast furnaces;
- o charge for steelmaking in the open hearth, BOF, Q-BOP furnaces or electric furnaces;
- o remelt in electric furnace for continuous casting detinning
- o raw material for ferroalloy production
- o precipitation iron

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[1] (See EPA-670/2-75-034 for details-available from U.S. Environmental Protection Agency).

- o cast steel

This same report suggested a wide variety of target specifications for various uses of ferrous metal which could be recovered from mixed MSW by means of ferromagnetic separation.

However, the most comprehensive set of guidelines for specifications for recyclable ferrous metals is promulgated by the Institute of Scrap Iron and Steel (ISIS) on behalf of the Institute's Specifications Committee. According to the ISIS report subtitled Specifications (available at nominal cost from ISIS):

> "Inasmuch as scrap usually originates in used materials, convering a wide range of sources, consumers generally exercise some tolerance with regard to size, and recognize further that some rust, scale, and dirt may adhere.
>
> "These specifications cover basic open hearth, basic oxygen, electric, and blast furnaces, plus foundry furnaces, including cupola, electric, and air. Specifications for cast iron grades are included, plus the specially processed grades and certain special grades for chemical use.
>
> "Railroad scrap specifications are included herein, as provided by the Association of American Railroads, plus grades for alloy scrap as promulgated by the Institute's Alloy committee.
>
> "Off-grade material and scrap containing residual material are defined, and the degree of cleanliness is described. Provisions are also made for deviations from the designated classifications.
>
> "Consumers may vary the existing specifications to conform with individual melting practices."

Well over 100 individual detailed specifications are included. These specifications are continually reviewed and ammended or supplemented as deemed appropriate.

NBS/ORM as mandated by Section 5002, has cooperated with ASTM (Committee E-38) in helping to develop and promulgate test protocols for recovery of ferrous materials; Dr. James Early of NBS has prepared a major review of ferrous scrap recycling in the U.S. dealing with its history, current status and possible future trends. (See publications list # 111). According to Dr. Early:

> "The secondary metals industry associated with the recycling of ferrous scrap is tied to the development in the 1850's of the acid-Bessemer furnace, the first large capacity steelmaking process. Within twenty-five years of this development, the recycling of ferrous scrap became an established industry. Changes in steelmaking technology since World War II, especially since the 1960's, are impacting the traditional ferrous scrap industry. The increased demand for old scrap is due to growth

in electric-arc furnace steelmaking capacity, reduced availability of home scrap and prompt industrial scrap, and larger scrap exports. Ferrous scrap recovered from municipal solid waste is one of the new sources of old scrap that may satisfy these increased demands. Systems for the recovery of the ferrous fraction from municipal solid waste have been developed, although increased usage of municipal ferrous scrap has been very slow due to institutional and technical barriers. The technical barriers posed by the physical and chemical characteristics of municipal ferrous scrap strongly inhibit the development of markets for this new material. The real and potential markets for increased consumption of municipal ferrous scrap are discussed in the review in terms of these barriers together with the important role of standards for municipal ferrous scrap in improving communications between buyers and sellers."

Present trends in steelmaking technology and ferrous scrap supply could result in increased demand for scrap including municipal ferrous scrap. The reduced size of automobiles will eventually reduce the supply of automotive scrap while changes in materials used in automobiles may lower the resulting scrap quality. Anticipated growth in continuous casting capacity with its lower scrap generation than ingot casting, and improved electric furnace productivity will reduce the quality of home scrap. Efforts by some steel fabricators to recycle their in-house scrap will reduce the availability of prompt industrial scrap. Finally, the continued growth of scrap-based electric-arc furnace capacity, combined with increasing overseas exports of scrap, will place added pressures on additional sources of scrap.

Table IV.2. reproduced from ASTM Standard E702-79, indicates currently accepted chemical and physical guidelines for specifications for municipal ferrous scrap.

IV.3.a.1.c. The glass fraction

Glass manufacturers use cullet (broken glass) as a fraction of the charge to their furnaces. This long established practice promotes the melting of raw materials and permits the reduction of furnace temperatures. Benefits of such practice translate into energy savings, extension of furnace linings life, and greater productivity. Most of the recycled cullet so far has been scrap glass from the manufacturing plant itself.

A potential new source of cullet is the glass contained in the municipal solid waste stream. Several large-scale reclamation facilities have been built and others are planned. These facilities will separate the glass fraction from the other components. The glass so recovered must meet stringent standards for quality and consistency (e.g., color, contamination, etc.). Targets for reclaimed glass specifications and test methods have been set for reuse in container manufacture. Tentative standards applicable to

Table IV.2. Currently accepted guidelines for specifications for Municipal ferrous scrap (From ASTM E702-79).

Chemical Requirements

Element	Composition, %				
	Copper Industry (Precipitation Process)	Iron and Steel Foundries	Iron and Steel Production[a]	Detinning Industry[b]	Ferroalloy Production
Phosphorus, max	...	0.03	0.03	...	0.03
Sulfur, max	...	0.04	0.04	...	...
Nickel, max	...	0.12	0.08	...	...
Chromium, max	...	0.15	0.10	...	0.15
Molybdenum, max	...	0.04	0.025	...	...
Copper, max	...	0.20	0.10	...	0.20
Aluminum, max	...	0.50	0.50	4.00[e]	0.15
Tin	...	0.03 max[d]	0.30 max	0.15 min[f]	0.03
Lead, max	...	0.03	0.15	...	...
Zinc, max	...	0.06	0.06	...	...
Iron (metallic), min	96.0	...	...	...	...
Silicon, max	...	...	0.10	...	...
Manganese, max	...	...	...	...	0.35
Carbon, max	...	...	...	...	0.6
Titanium, max	...	...	...	...	0.025
Total combustibles, max	0.2[c]	4.0	4.0	...	0.5[g]
Metallic yield, min	...	90.0	90.0	...	90.0

[a] Experience has shown that material which has been incinerated probably will not meet these requirements.

[b] A minimum of 95 weight % of the material delivered shall be magnetic. Nonmagnetic material attached to the original magnetic article may be included in the minimum requirement.

[c] The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

[d] For steel castings, the requirement for tin content is 0.10 max %.

[e] Not based on melt analyses due to aluminum losses during melting; to be determined by a method mutually agreed upon between the purchaser and supplier.

[f] Refer to sections on magnetic fraction and chemical analysis of tin in Methods E 701. Normal separation of white goods and heavy iron yields tin contents equal to or greater than 0.15 weight %. Lesser tin contents would impact severely the value of the scrap to detinners.

[g] The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

TABLE IV.2 (cont'd)

Physical Requirements

End-Use	Bulk Density, lb/ft^3 (kg/m^3)	Form
Copper Industry (Precipitation Process)	30 (480) max	loose, shredded as agreed upon between purchaser and supplier, shall not be balled or baled[a]
Iron and Steel Foundries	50 (800) min	loose, balled, or baled[b] as agreed upon between purchaser and supplier
Iron and Steel Production	75 (1200) min	loose[c] or baled[b] as agreed upon between purchaser and supplier
Detinning Industry	25 (400) max	shredded, 95 weight % shall be -6, +½ in. (-152, +12.5 min); shall not be balled, baled, burned, incinerated, or pyrolyzed
Ferroalloy Production	50 (800) min	loose, as agreed upon between purchaser and supplier

[a] Various consumers may establish gage limitations on the material they purchase.

[b] Industry practice is to specify a maximum bale size that may vary amo users.

[c] Experience has shown that if the size range is 95 weight %, -2, +¼ in (-50, +6.3 mm), the bulk density requirement can be met and the mater will be loose and free flowing.

the manufacture of glass wool insulation are currently under review.

NBS/ORM cooperated with ASTM Committee E-38 on Resource Recovery, the glass industry, reclamation facilities, and the National Center for Resource Recovery. These activities contributed to the generation of two standards for recovered glass specifically for reuse in container manufacturing. These standards are ASTM E688, Standard Methods of Testing Waste Glass as a Raw Material for Manufacture of Glass Containers and ASTM E708, Standard Specification for Waste Glass as a Raw Material for the Manufacture of Glass Containers. These standards constitute the present guidelines for specification for reuse of glass destined for waste.

NBS/ORM also cooperated with ASTM and the glass industry on technological problems that might be encountered when using recovered glass in manufacturing. The objective in this area was to assess potential limits on the use of reclaimed glass. Examples of such barriers to recycling are the influence of color mixture and refractory contamination in glass production.

Color mixed glass when added to a batch formulated for a particular glass color is a problem. Oxides of chromium and iron are the main coloring agents used in container manufacture. For example, concentrations of Cr_2O_3 by weight percent are 0.0015 (flint), 0.025 (amber), and 0.27 (green). Therefore, only minute quantities of amber or green colored glass can be accepted in flint.

Refractory contaminants (e.g,. pieces of ceramics, gravel, concrete, spark plugs, etc) are especially troublesome in glass manufacture. The particles, depending on their size, often do not melt in the glass furnace. Such particles are the source of "stones" in the glassware in which case the product must be rejected for aesthetic reasons or structural weakness. The latter is especially important in minimizing safety hazards, especially for carbonated beverage containers.

NBS Testing Evaluations

NBS carried out testing of samples from initial glass recovery operations from a mechanical sorting plant dealing with mixed MSW. Test methods cover determinations of moisture content, organic contamination, magnetic/non-magnetic contamination, color fraction, particle size distribution, refractory content, and melt evaluations. Results of these tests indicate that the overall quality of recovered glass falls short of meeting ASTM E708 established acceptance standards for waste glass as a raw material for the manufacture of glass containers.

Data for these tests, performed in accordance with ASTM for E688 are presented in tables IV.3-6. Viscosity parameters, although not listed in the ASTM specifications, are very important in the forming processes for glass containers. All samples used in the

Table IV.3. Source 1 (Flint, Color Sorted) (11.6 lbs, material greater than 6 mm).

	Sample	ASTM Specs[a]
Moisture (%)	Dry	0.05 % wt
Non-Glass Contaminants:		
Organics (%)	0.5	0.2 max
Magnetics (%)	0.15	0.05 max
+ 1/4" particles	2	0
Non-Magnetic (%)	0.4	not available
+ 1/4 particles	6	not available
+ 20 particles	13	1/40 lbs
Inorganics + 20 (%)	0.45	0.1
Refractories		
+ 1/4" particles	3	0
+ 20 particles	7/lb	1/40 lbs
- 20, + 40 particles	11/lb	2/lb
- 40, + 60 particles	27/lb	20/lb

---

[a] ASTM specs have not been developed for this material. ASTM specs listed are for recovered material 6 mm or less in size.

Table IV.4. Source 1 - Color Distribution (2 kg, Color Sorted Flint).

	Sample	ASTM Specs
Flint, %	92.6	95-100
Amber, %	4.1	0-5
Green, %	2.3	0-1
Other Colors, %	1	0-0.5

Melt Test

Poor quality glass, dark emerald green.

Table IV.5. Froth floated samples.

	Source 2 (1.3 kg)	Source 3 (1.7 kg)	Source 4 (1.9 kg)	ASTM Specs
Moisture (%)	Dry	Dry	Dry	0.5 wt
Organics (%)	0.7	0.9	0.6	0.2
-140 Screen (%)	28	24	30	15
Refractories (Particles):				
+ 20	3	2	1	1/40 lbs
- 20, + 40/lb	6	11	9	2
- 40, + 60/lb	30+	30+	30+	20
Non-Magnetic Metals:				
+ 20 particles	4	7	5	1/40 lbs
Melt Test	poor quality (scummy)	--	--	N/A

Table IV.6. Viscosity data (Source 4).

Log_{10} Viscosity (poise)	Temperature (°C)
3.50	1130
3.0	1220
2.75	1275
2.50	1335
2.25	1400

These data were fitted by a simple linear regression expression as $\log_{10}$ Viscosity (poise) = 8.66 - 0.0046 T (°C)

As a comparison for NBS-SRM 710, Soda-Lime Glass: $\log_{10}$ Viscosity (poise) = 8.21 - 0.0044 T (°C)

(Range of validity of both expressions $1075 \leq T\ (°C) \leq 1425$)

above tests were labeled as: source 1, source 2, etc., depending upon specific source.

Cooperative Testing Activities

NBS cooperated with the National Center for Resource Recovery, EG&G, and Owens-Illinois on modifications and testing plans for Recovery I, a mechanical separation plant in New Orleans. For this activity, data on Refractory Count for Recovery I samples obtained by Owens-Illinois and NBS are presented in table IV.7. All samples submitted met the Refractory Specifications of ASTM E708. However, the validity of the tested samples is in question since no sample description and/or sampling procedures were provided.

IV.3.b. The organic fraction of MSW

This fraction comprises about 80 percent of total MSW generated. Table IV.8 indicates the basic components of this fraction as well as the percentage of each.

The organic fraction can be burned, either in the form as-received MSW, or as converted to various forms of refuse derived fuels (RDF) in order to reclaim energy-from-waste. ASTM E-38 designations for various forms of RDF are:

RDF-1: Wastes used as a fuel in as-discarded form
RDF-2: Wastes processed to coarse particle size with or without ferrous metal separation
RDF-3: A shredded fuel derived from municipal solid waste (MSW) that has been processed to remove metal, glass, and other inorganics. This material has a particle size such that 95 weight percent passes through a 2-in. (50-mm) square mesh screen.
RDF-4: Combustible waste processed into powder form, 95 weight % passing 10-mesh screening
RDF-5: Combustible waste densified (compressed) into the form of pellets, slugs, cubettes, or briquettes.
RDF-6: Combustible waste processed into liquid fuel.
RDF-7: Combustible waste processed into gaseous fuel.

MSW - Unprocessed (or minimally processed) raw municipal solid waste - equivalent to RDF-1.

A number of questions and challenges are posed in dealing with the organic fraction. Among these are:

- Should certain fiber based materials, e.g., newsprint, boxboard, be separated out and recycled back to fiber based products?

- Should raw MSW be fired on a mass basis as the most economical means to reclaim value from the waste?

- Is there a stable market for some or all forms of energy-from-waste (EFW)? If so, what forms?

Table IV.7. NCRR Recovery I Glass Project Refractory Particles (450 g).

Sample Data (week of)	Lab[a]	+2.65 sp. gr. (g.)	Number of Particles		Type
			(+40)	(-40, +60)	
6/29/81	A	0.3	0	1	Corundum
	B	0.4	0	2	Corundum
7/6/81	A	0.2	0	2	Corundum
	B	0.3	0	1	Corundum
			0	1	Silicon Carbide
7/20/81	A	0.5	0	1	Corundum
	B		0	2	Silicon Carbide
		0.4	0	2	Corundum
7/27/81	A	0.4	0	0	
	B	0.3	0	1	Corundum

[a] Cooperating Laboratories: Owens-Illinois, National Bureau of Standards.

TABLE IV.8.

Material	Percent of Total
Paper	32.4
Plastics	3.2
Rubber	2.1
Leather	0.5
Textiles	1.5
Wood	3.5
Food wastes	16.8
Yard wastes	19.1

Source: U.S. EPA Publication SW-600 (1977) P. 18

- Is conversion to some form of RDF sensible from an economic, technical and marketing viewpoint?
- How do local, state and federal statutes affect the flow and usage of various forms of materials used to generate EFW?
- What "side effects", e.g., production of potentially dangerous pollutants, corrosion of boilers, might result from use of EFW?
- What steps are necessary to characterize various forms of materials which may be used to generate EFW?
- What are the trade-offs between direct recycling and burning to create EFW?

While ORM examined many of these questions, the first to be addressed was that of characterization. Our view was that until appropriate sampling and characterization techniques were developed, no solid basis of comparison would exist for dealing with most of the other questions. Therefore, with aid, advice, and encouragement from ASTM, ASME (American Society of Mechanical Engineers) and other federal agencies, ORM began systemmatic efforts to develop test methods, procedures, and standards to aid in characterization of the various materials, combustion processes, emissions and other effects relevant to EFW. (See Publications List #'s 39-45, 55, 57-59, 61-68, 71-73 for specific results.)

ORM staff, in cooperation with ASTM, have contributed significantly to no fewer than ten standards listed in the 1982 Annual Book of ASTM Standards:

E711-81	Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter
E775-81	Standard Test Methods for Total Sulfur in the Analysis Sample of Refuse-Derived Fuel

E776-81	Standard Test Method for Forms of Chlorine in Refuse-Derived Fuel
E777-81	Standard Test Method for Carbon and Hydrogen in the Analysis Sample of Refuse-Derived Fuel
E778-81	Standard Test Methods for Nitrogen in the Analysis Sample of Refuse-Derived Fuel
E790-81	Standard Test Method for Residual Moisture in a Refuse-Derived Fuel Analysis Sample
E791-81	Standard Method for Calculating Refuse-Derived Fuel Analysis Data from As-Determined to Different Bases
E829-81	Standard Method of Preparing RDF-3 Laboratory Samples for Analysis
E830-81	Standard Test Method for Ash in the Analysis Sample of Refuse-Derived Fuel
E856-82	Standard Definitions of Terms Relating to Physical Chemical Characteristics of Refuse-Derived Fuel.

IV.3.b.1. Calorimetirc characterization of refuse derived fuels

Recent NBS/ORM efforts have been devoted to development of a calorimeter in which to determine the calorific value of kilogram-size samples of minimally processed municipal solid waste (MSW). A large scale calorimeter affords greater credibility because kilogram-size samples of MSW should represent the properties of the heterogeneous bulk material more reliably than the highly processed gram-size samples currently used in bomb calorimetric determinations.

E 711, Test for Gross Calorific Value of Refuse-Derived Fuel (RDF-3) by the Bomb Calorimeter, published in Part 41 of the 1982 Annual Book of ASTM Standards, is available to analysts throughout the world. This method uses a one gram sample to determine the gross calorific value of RDF-3. Many engineers feel that one cannot sample MSW or RDF accurately using one gram. Moreover, they also feel that processing to 0.5 mm particle size--as directed in the ASTM E829 Method for Preparing RDF-3 Laboratory Samples of Analysis - could change the sample chemically so that it no longer resembles the original MSW or RDF. The development of a flow calorimeter by NBS/ORM which can accommodate a 2.5 kg sample provides greater credibility with respect to representing the true properties of the original refuse sample. The comparison of calorimetric data derived from both the one gram capacity bomb calorimeter and 2.5 kg capacity flow calorimeter should furnish test laboratories with the kind of assurance they need regarding the accuracy of determinations of calorific values.

In the past year, three lines of work have been emphasized: a) Oxygen flow calorimetry of solids; b) Oxygen bomb calorimetry of solids; and c) Laboratory scale fluidized bed combustion studies comparing combustion characteristics of some coals with some RDF's.

IV.3.b.2. Oxygen flow calorimetry of solids

The 2.5 kg capacity flow calorimeter, shown in Figure IV.1 has been used to burn pellets of minimally processed waste (RDF-2). The major components of the calorimeter (see A, B, E, F, and H of figure) have been fabricated and installed in a new laboratory facility in the Mechanics Building of NBS. Design of the auxiliary parts of these major components and also the accessory components of the calorimetric system have been completed. Fabrication, assembly, and testing is in progress: A 2.2 kg RDF-2 sample was combusted in 30 minutes time which is well within the acceptable limit of 18 minutes per kilogram. In the second trial experiment, the controllers for the oxygen supply to the combustor and the color video monitor for viewing the sample were tested. During the last quarter of FY 1982, the calorimeter was put into operation and four calorimetric runs completed--two calibrations with cellulose and two heats of combustion of RDF-2. In FY 1983, a comparative study will be done to determine if there are significant differences between the heating value of MSW obtained by using 2.5 kg processed samples and 1 g processed samples.

IV.3.b.3. Oxygen bomb calorimetry of solids

Industry and test laboratories have expressed a need through ASTM Committee E-38 on Resource Recovery for a secondary standard for determining the heating value, ash and moisture content of RDF. For this purpose, a synthetic RDF consisting of 80 percent cellulose and 20 percent non-combustile materials (15 percent silica and 5 percent alumina) was prepared by NBS/ORM in collaboration with ASTM Subcommittee E-38.01 on Energy. Two different formulations of this material were submitted to eleven different laboratories for Round Robin Testing. The essential difference between the formulations was that the second contained non-combustible material having a more uniform particle size (about 50 micrometers). The participating labs in the two Round Robins (including NBS) provided NBS/ORM with data on the heating value, moisture, and ash content of each formulation. The interlab agreement of the results on the second (i.e., final) formulation was improved (a factor of three in the heating value and five in the ash content) and was comparable to that obtained in a previous Round Robin with NBS SRM Bituminous Coal 1632a. As a result of these findings, the NBS Office of Standard Reference Materials has approved funds toward certification of this synthetic RDF as an SRM.

Objectives to be attained by using the 2.5 kilogram capacity flow calorimeter in FY 1983[2]:

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[2] FY 1983 funds from Department of Energy, Energy from Municipal Waste Division.

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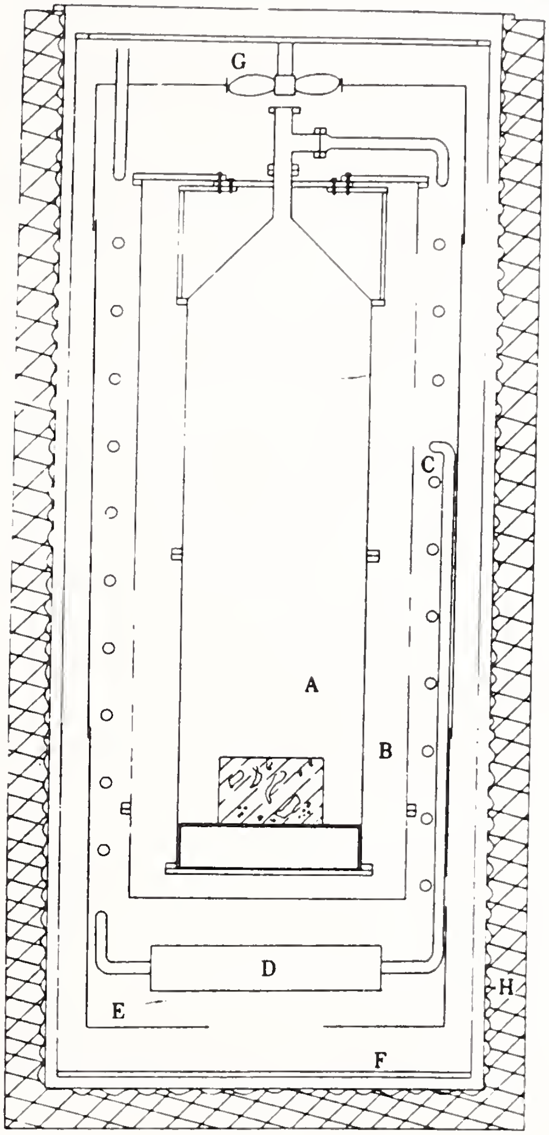


Figure IV.1. The 2.5 Kilogram Capacity Flow Calorimeter. A denotes the combustor, B the combustor enclosure, C the exhaust cooling coils, D the exhaust condenser, E the flow shield, F the calorimetric vessel, G the stirrer and H the water wall enclosure.

- Combustion data which characterizes refuse and is applicable to the design and operation of incinerators and boilers. Development of a fundamental scientific approach to the operation of incinerator systems should replace the empirical approach

- A comparison of calorific values determined on highly-processed samples of refuse in 2.5 kg capacity and 1 gram capacity combustion calorimeters.

- A comparison of calorific values of the both highly-processed and minimally-processed refuse determined in the 2.5 kg capacity calorimeter.

- Determination of the variability of minimally-processed refuse over a two-week period and comparison of calorific values determined in the 2.5 kg capacity and 1 gram capacity calorimeters.

Future Research Objectives

- Perform combustion calorimetry on refuse samples under excess-air, stoichiometric-air, and starved-air conditions.

- Identify the threshold conditions for the formation of incomplete combustion products (CO, soot/carbon, hydrocarbons) and volatile pollutants containing sulfur and/or chlorine (CO, soot/carbon, hydrocabons) and volatile pollutants containing sulfur and/or chlorine (SO_2, HCl) in calorimetric measurements using air rather than oxygen to support combustion.

- Compare data on calorific value, composition of ash, volatile combustion products, and temperature profile of the combustor between combustion measurements carried out in oxygen and varying amounts of air.

- Perform combustion studies on synthetic hazardous wastes using large (2.5 kg) samples so that detection of the kind and amount of effluent can be carried out to high destruction efficiencies. Determination of calorific value, temperature profile of the combustor, composition of the waste and ash residue would be included.

- Perform combustion studies on coal-RDF mixtures. If oil and natural gas supplies undergo shortages and/or increases in price, coal and alternative fuel (i.e., RDF) will increase in demand and usage. Power companies will again accept processed refuse to be burned with coal in their boilers. No data-base is available on the combustion characteristics of coal-RDF mixtures.

IV.3.b.4. Combustion of refuse-derived fuels in a laboratory scale fluidized bed furnace

Over the years a large amount of information has become available on various aspects of coal combustion in small-scale laboratory furnaces. This information forms a body of basic data which a combustion engineer can draw upon as a rough but useful guide for prediction of coal combustion characteristics in industrial boilers and furnaces. Among the most important data available from laboratory experiments are fuel burning rates as a function of both fuel properties and parameters of gas streams surrounding the fuel particles. This information is required for estimation of key boiler parameters: rate of heat release, furnace retention time, completeness of combustion, and furnace outlet temperature.

The equivalent laboratory information does not exist for refuse-derived fuels (RDF). The objective of the present project was to fill some of the data gaps by laboratory-scale measurement of air-entrainment and combustion of RDF. Most of the combustion data were obtained in the entrained mode with the view of application to pulverized fuel and semi-suspension boilers.

The project was accomplished in four tasks: 1) a laboratory study of entrainment characterization of RDF; 2) a "baseline" study of combustion of lignite particles in a laboratory furnace constructed at NBS for that purpose; 3) combustion of RDF in the same furnace; and 4) a survey of capability, outside NBS, required for pilot tests of RDF combustion. Brief summaries of these four tasks are given in sections 1 through 4. Section 5 lists the documents, existing or in preparation, on this project.

IV.3.b.4.1. Entrainment of RDF particles

The fact that even well prepared RDF samples (e.g., RDF-3) consist of particles having a variety of shapes, sizes, and densities, introduces a serious problem of entrainment characterization. Whereas pulverized coal particles can be considered quasi-spherical (all three dimensions of the same order of magnitude for the purpose of engineering estimates of settling velocities, burning rates and furnace retention times), this is not true of RDF. To address the entrainment problem, a cold-flow elutriation apparatus (CFEA) was constructed and used to measure settling velocities for particles of various shapes, sizes, and densities. Correlations were then developed allowing prediction of entrainment velocities and of maximum particle sizes entrainable under condition representation of boiler furnace gas streams.

For quasi-spherical particles some widely used correlations, examined in the light of our experimental results, were found to give erroneous predictions because of improper definition of flow regimes. Composite correlations, based on four different regimes (Stokes, intermediate I and II) and Newton's) were found adequate for predictions in boiler furnace gases, e.q., the maximum diameter of a solid piece of wood entrainable at 30 ft/sec and 1500 °F is 0.134 in, corresponding to sieve Mesh 6.

Extensive CFEA data were taken, and correlations for furnace gases were developed, with particles of increasingly irregular shapes: circular discs and oblong discs with decreasing thicknesses, down to newsprint paper. In particular, it was found that in the intermediate regimes many of these showed increased drag coefficients with the Reynolds number, leading to high entrainability. This trend is a departure from the conventional drag-coefficient curve, but is in second with some recent data for thin platelets.

The CFEA was also used to measure the range of settling velocities of sieved fractions of RDF-3. Of special interest to this study was the -20 + 35 Mesh fraction, the settling velocities of which, while covering a very wide range, are comparable to those of pulverized coal (see Section 3).

IV.3.b.4.2. Combustion of lignite particles

A laboratory furnace was constructed and used for combustion of particles. The furnace has a rectangular cross-section, 5.5 x 4 inch, is 13 inches high, and has two glass walls for full view of its interior. Furnace gas temperatures and velocities ranged up to 1650 °F and 5 ft/sec, with widely variable oxygen content. Burning times of individual particles were determined photographically with light chopping at 600/sec.

The fuel chosen for a baseline combustion study was a type A lignite, 30.4 percent moisture, 7.9 percent ash, 7570 Btu/lb (as received). Two samples -140 + 170 Mesh, and -200 +230 Mesh were used for detailed particle burning-rate studies. The gas temperature was kept constant t 1610 ± 30 °F, while the oxygen content of the furnace gas was varied. Particles were injected into furnace gas horizontally from the sidewall through a small (1/8 inch) tube.

It was found that at high oxygen contents (oxygen-enriched air to the gas burner), the experimental rates agreed with the established correlations for rapid, diffusion-controlled combustion of coal particles. This result indicates that the furnace is adequate for quantitative particle-combustion studies. Transition to slow, incomplete combustion was found to take place when the oxygen content was decreased below 19 percent for the 140/170 Mesh sample or below 14 percent for the 200/230 Mesh sample. While these oxygen constants are still much higher than in actual boilers, these results are not surprising, because our experimental temperatures--chosen for RDF combustion studies--were lower than in coal boilers.

IV.3.b.4.3. Combustion of RDF particles

Two sets of experiments were performed: pure suspension combustion of samples from a batch of Teledyne National RDF is, pulverized and sieved, -20 + 35 Mesh; and combustion of larger samples (between 6 and 14 Mesh) from the same batch burning partly on a grate and partly in suspension.

The pulversized samples were burned under the same conditions as the lignite samples (see Section 2), except that in some runs the gas temperature was even lower. The sieve fraction, -20 + 35 Mesh, was chosen because we found that most of this material ignited before settling to the bottom of the furnace and then burned entirely in suspension, just as the lignite samples. (It is probable that some solid non-combustible particles--e.g., dirt or glass pieces--settled to the bottom without affecting the combustion of the bulk of entrainable material; see Section IV.(3)b.4.1.).

Combustion of pulverized RDF was found to be different from combustion of lignite powder in at least three ways. First, RDF particles, although larger than lignite samples, burned down to lower gas oxygen contents than lignite: e.g., 11% O_2 at 1550 °F was sufficient for ignition of many particles. Second, the average burning times of particles were longer than for lignite sizes reported in Section IV.(3)b.4.2. Third, the range of burning times was very wide.

It must be re-emphasized that these comparisons are not made for particles of comparable sizes (RDF vs lignite), but of comparable entrainability. This type of comparison appears to be much more useful, because it is more indicative of the tendency for carryover of clear char from the furnace. Specifically, for the particle size studied, it shows that even when given adequate temperature for ignition and adequate oxygen for combustion, some constituents of RDF will require longer time for complete combustion than lignites.

To explore the question of carryover somewhat further, we made a limited number of tests with RDF sizes large enough to drop onto a grate (Nichrome mesh) near the bottom of the furnace. Two samples were used: -6 + 8 Mesh and -12 + 14 Mesh. Combustion was observed by high framing photography. As suspected, we observed that some particles, after burning on the grate for a relatively long time (0.1 to 1 sec), lifted and continued to burn in suspension for a similar period of time. This result confirms that it is not so much the original fuel particle size that matters, but the size (and shape and density) at which the particle becomes entrainable.

IV.3.b.4.4. Sub-scale pilot requirements

The two objectives of this task were:

1) Survey of industrial facilities suitable for sub-scale combustion of RDF;

2) definition of a program plan for obtaining generic design data applicable to suspension combustion of RDF in boilers.

Three industrial test facilities have been selected as being applicable for generation of data for suspension combustion of RDF. In addition, ancillary spreader-stoker data would be most desirable; a model furnace at the University of Utah, Salt Lake City, Utah, is uniquely suitable for supplying these data.

IV.3.b.4.5. Documentation

1) S. R. Charagundla and A. Macek: "Entrainment Characteristics of Particles in Gas Streams." In preparation.

2) A. Macek and S. R. Charagundla: "A Laboratory Approach to Obtain Suspension Combustion Data for Refuse-Derived Fuels." DOE/ANL Workshop: Converting Waste to Energy, ANL/CNSU-TM-96, Feb. 1982.

3) A Macek and S. R. Charagundla: "Burning Rates of Lignite Particles". Submitted for presentation of Combustion Institute Meeting, Eastern Section, Atlantic City, N.J., Dec. 1982.

4) A. Macek and S. R. Charagundla: "Burning Times of Pulverized RDF." In preparation.

5) A. Macek: "Combustion Characteristics of RDF, Phase II." Final Report submitted to DoE, Nov. 13, 1981.

As noted previously, details of NBS/ORM efforts to develop test methods and standards for the characterization of MSW and various forms of RDF can be found in the NBS/ORM Publications List (Appendix I) through reference to the following numbers: 39-45, 55, 57-59, 61-68, 71-73.

In addition to these efforts, NBS/ORM and the Government of Japan cooperated on a study dealing with the pyrolysis and subsequent gasification of a large amount (40 tons) of commercially produced U.S. refuse derived fuel. Details regarding this project are included in the Section dealing explicitly with the special cooperative venture with Japan. (Section X.(2)e).

IV.3.c. Combustion process characterization

Combustion of MSW or any form of RDF results in off-gases which have the potential to adversely affect air quality. In the case of one waste-to-energy facility, emission of low levels of dioxin was detected. The end result was that the facility representing over $150 million in capital costs--was required to suspend operations in late 1982. Fear of dioxin emissions led to suspension of efforts to establish a waste-to-energy plant at the Brooklyn Navy yard. Therefore, the thermodynamics and kinetics of the combustion process need to be better understood in order to minimize the probability that unsafe concentrations of pollutants will be emitted by a waste burning facility.

IV.3.c.1. Development of chemical and kinetic techniques

Efforts were made to characterize both the combustion process and the mechanisms underlying formation and possible escape of resultant pollutants. (See ORM Publications List Numbers 118, 119 and Appendix III for detailed results). In the past year, work in this area has been concerned with the demonstration of the applicability of thermal analytical techniques for the characterization of the pyrolytic and oxidative properties of refuse derived fuels. The important thrust of this program has been the application of these methods (High Pressure Differential Thermal Analysis and Thermal Gravimetric Analysis) and developmental work on an associated technique, Evolved Gas Analysis. With respect to HPDSC and TGA, a broad quantitative data base on assorted RDF and coal samples has been accumulated. Coal samples are indicative of the variations that can be expected in commercial samples and the basis for comparisons with coal established. The conditions for determining accurate heats of formation have been derived.

In cooperation with the experimental program in the NBS Chemical Engineering Center partially combusted RDF and coal samples have been analyzed. It has proved to be possible to make satisfactory thermal analytical measurements on samples with combustible carbon samples having accuracy in the few percent range. The thermograms have proved to be interesting in that although the volatile peaks are gone, the char peaks remain, except that they are in the lower temperature ranges. This is indicative of great reactivity. An attempt is underway to relate these observations with the parameters of the combustion experiments [flame length, excess oxygen, feed rate, etc.] which produced the partially combusted samples. With respect to the uncombusted samples, it is clear that RDF samples will in general prove to be more readily ignitable than coal samples. This is brought about by the presence of plastics (polyethylene?) and may well pose a spontaneous ignition hazard. The thermograms that have been obtained contain phenomonological kinetic information. Indeed the presence of each distinct peak is indicative of a specific reaction process. We are in the process of reducing the data on char oxidation within such a context. In the case of the coal samples, kinetic data obtained on the basis of other techniques exist; thus, there is a basis for comparison. We are particularly interested in comparing results from RDF and coal char samples, since one expects that such information will be relatable to burn-off.

Our interest in Evolved Gas Analysis is due to the fact that such studies yield more "chemical" type information as compared to the heat and weight changes from DSC and TGA type experiments. Furthermore, it should be possible to carry out heating experiments at rates considerably faster than the 100°/min used in the former systems. Two devices have now been set up and are being tested. One of these involves coupling a gas chromatograph to the existing TGA apparatus, so that at selected temperatures during a run, a gas analysis can be carried out. The other couples infra-red cells pyrolyzer where flash heating is effected on a platinum ribbon or coil. The major problem has been the generation of reproducible data. Up to the heating rates of the DSC and TGA apparatus, these problems have now been surmounted. Results are in very good agreement with those from the other techniques. Current work is concentrated on making results more quantitative and moving on to more rapid heating times. With respect to the former, there is a need for internal calibration, and we have been carrying out extensive studies with well characterized polymers.

IV.3.c.2. The dioxin emission issue

Dioxin which might arise from combustion sources is of major concern to the U.S. incinerator community and to the public. This problem caused the Research Committee on Industrial and Municipal Wastes of the American Society of Mechanical Engineers to sponsor an interdisciplinary "Study on State-of-the-Art of Dioxin from Combustion Sources" (ASME-New York 1981). Therefore, processes which may contribute to the formation of polychlorinated dibenzo-p-dioxins (PCDDs) were investigated. A model mechanism was constructed to investigate the possibility for homogeneous gas phase formation of PCDDs from polychlorinated phenols in an incinerator environment. Numerical calculations lead to the conclusion that the probability for gas phase formation of PCDDs is likely to be very low at high temperatures if mixing between fuel and air is efficient. Effects of use of auxiliary hydrocarbon fuel and excess air as well as probable sources of non-idealities and the potential role of non-gas phase effects were considered. The results indicate that dioxin formation tends to occur in the incinerator as a result of such processes as mixing inhomogeneities between fuel and air and/or surface reactions. Perhaps, then, dioxin emissions can be minimized either with or in a combination of optimized incineration design, operation and maintenance. (Details of this work can be found in Appendix III).

The propensity for the incinerator to produce chlorinated emission products is very likely to depend in some fashion on the chlorine content of the fuel. Tests for chlorine content and sulfur content were carried out; samples were taken on consecutive days from a commercial plant which produces fuel grade RDF-2. The results are shown in table IV.9. Clearly, incinerator and boiler operators utilizing waste fuel sources should find it advantageous to monitor chlorine content; emissions from the facility should also be monitored carefully on days when high chlorine fuels are fired.

Table IV.9. Chlorine and sulfur contents of commercial samples of RDF-2 (Winter 1980). Moisture free basis

Day	% Chlorine	% Sulfur
1	0.40	0.17
2	0.96	0.14
3	0.61	0.12
4	0.55	1.38
5	0.44	0.13
6	0.69	0.27
7	1.59	0.30
8	0.51	0.08
9	0.49	0.11
10	0.57	0.88

IV.3.d. Corrosion Studies

Another characteristic of refuse based fuels which needs to be well understood is the propensity for these fuels to cause boiler material degradation. Therefore, NBS designed special corrosion probes; two of these have been installed in boilers co-firing coal and RDF. The first of these was installed March 11, 1982, at the NASA/Langley facility. The other was installed August 24, 1982, at Wright-Patterson Air Force Base in a similar boiler. Because of the short time since insertion of these devices, only preliminary data are available from the NASA facility; none are available from the Air Force facility as yet.

With regard to the investigation at NASA/Langley, the probe was constructed to expose four sets of five different alloys. These alloys are three stainless steels designated as SA213-T11, SA213-T22, and SA213-TP304, and two alloy steels designated as SA192, and SA178. These materials were exposed to a controlled temperature range of from 100 °C to 388 °C when the incinerator is at full heat and above 400 °C in the area of the probe. Prior to the installation of the probe, a special trip was made to the NASA incinerator facility to determine the final details of sources for power, compressed air, and cooling water. Exact dimensions for the "door" which holds the probe in place were also determined. The corrosion probe and associated monitoring equipment were installed on March 11, 1982. Since that time, temperature data have been automatically measured at four points along the probe, recorded, and sent to NBS/ORM for evaluation. These data indicated that over the period of exposure the temperature fluctuated by hundreds of degrees from a minimum of 100 °C to a controlled maximum of 387 °C. This set of data does not include temperature changes during periods when the incinerator was shut down which causes the measured temperature to approach normal room temperature (25 °C).

On September 28, 1982, six months after initial exposure, the probe was withdrawn from the incinerator and the specimens removed for analysis. Initial visual examination revealed some pitting on the materials. New specimens were added in place of those removed and the probe reinserted for a second period of exposure. Further results will be obtained from this facility and from the Air Force facility in FY 1983.

IV.4. Fibre and Wastepaper

Recycling of waste fibre is carried out in many parts of the United States. According to the American Paper Institute, about 18 million tons of newsprint, boxboard and other fibres are recycled into new raw material each year. These fibres are always source separated from the remainder of the waste. The National Association of Recycling Industries (NARI), as well as individual dealers and jobbers have developed specifications for these goods. The NARI specifications are updated periodically and serve as the basis for many, if not most, market transactions (The most recent NARI specifications are available from NARI headquarters in New York City).

Some efforts have been made to reclaim useable fibre from mixed wastes; these attempts have met with varying degrees of success--most notably for production of low grade tissue in Japan. But these processes do not yet appear ready for wide scale commercialization on an economically sound basis.

Key issues affecting supply, demand, and market fluctuations for waste fibres are only weakly dependent on specifications. Therefore, NBS/ORM chose not to investigate technical aspects of guidelines for specifications for waste fibres. Rather, ORM chose to examine the trade-offs between various uses for the fibre and resultant options for either recycling into paper products, burning to claim energy or other recycling options, e.g., for cellulose based insulations. The results of these investigations are discussed in the Section dealing with NBS/ORM response to Section 5003 of P. L. 96-482 dealing with markets. (See also Publ. List #78).

V. SPECIAL WASTE CATEGORIES

V.1. Used Tires

NBS/ORM did not use empirical methods to characterize used tires in its effort to develop guidelines for specifications for various uses. The reason for this was that ORM personnel, in a survey made in 1978, ascertained that, to a reasonable first approximation, a possible reuse-recycling protocol for discarded tires is:

1) Retread and reuse to end of carcass life;
2) Render into crumbs for various uses--this process implies shredding of the original tire.
3) Use shredded tries as supplemental fuel.
4) Pyrolize shredded tires.

(See ORM Publication List #75 for details)

V.1.a. Retreading

By far, the best possible course of action is to retread and reuse all eligible tire carcasses since this process "recovers" considerable material which otherwise would be destined for waste. Note that roughly 175 million new tires and 50 million retreads were sold in the replacement tire market in 1979. That means approximately 225 million worn tires were taken out of service and replaced with either a new or retreaded tire. In addition, new cars, trucks, and buses, were equipped with about 62 million new tires in 1979--51 million passenger tires and 11 million truck-bus tires were taken out of service on scrapped vehicles. In total, approximately 260 million tires were potential candidates for disposal as solid waste. Approximately 40 million to 50 million of them were retreaded--15 percent to 19 percent. An additional 10 to 15 percent of the worn out tires were to be used for other productive purposes such as reclaimed rubber for recycling into new rubber products, fuel, breakwaters and artificial reefs, dock bumpers, playground equipment, roadside impact absorbers, and construction materials. The remaining 70 to 75 percent of the worn out tires, about 180 million, were disposed of in non-productive ways--mainly in landfills. Based on industry data one can estimate oil consumption at about 25 gallons per hundred weight of tires produced--about 20 gallons for the materials and five gallons in the manufacturing of tires. The total weight of the 180 million tires which were non-productively disposed of in 1979 was approximately 7 billion pounds, representing the consumption of 1.75 billion gallons of oil--40 million barrels.

The 650 million plus pounds of tread rubber consumed in the production of the 50 million retreads sold in 1979 provided the equivalent service of 2.3 billion pounds of new tires. At 20 gallons per hundred weight of tires, the oil savings from raw materials production alone was 330 million gallons--more than 20 thousand barrels per day. Additional energy savings are realized during the manufacture of retreads versus new tires. With the current product mix of passenger, truck and other retreads, the average oil savings in raw materials alone for a retread over a new tire is about seven gallons per tire--a 70 percent savings.

There exists a varying degree of acceptability of retreaded tires, as is the case with most recycled products. One out of five new replacement passenger car tires is a retread, while 90 percent of the world's airlines use retreaded tires. A majority of trucks drive on retreads (about 1.1 retreaded truck tires are sold for every new truck tire installed). Nearly 60 million worn tire casings that could be retreaded as discarded every year. The American Society for Testing Materials has developed a recommended practice for the inspection of these casings prior to retreading. (See ASTM Book of Standards, Volume 38: F393-74 for details).

V.1.b. Waste Tires As Fuel

While ORM Publication List Reference #75 lists many possible uses for waste tires that cannot be retreaded, the easiest task which might reclaim something useful from such tires is to use shredded tires as supplemental fuel in a waste-to-energy plant or appropriate industrial boiler. Table V.1 taken from a report by R. H. Taggart (GMC, Warren, Michigan) lists pertinent data for rubber to be used as a supplemental fuel. Taggart also measured air emissions over a six month test burn involving a coal-10 percent rubber mixture. Particulate emissions increased but SO_x actually fell. The ZnO component played no significant role. Odors were not a problem.

Since approximately one tire for each person in the U.S. is discarded annually, of which about 20 percent are retreaded, a population center containing 200,000 persons could be expected to yield about 150,000 tires annually or about 1500 tons of combustible chips. Allowing for energy to transport and shred these tires, as well as a boiler efficiency of 0.67, these tires, if burned, will yield a net gain of over 25,000 MBTU annually; the net dollar gains will be somewhere between $50,000 and $100,000 annually.

Shredders which will provide required chips are readily available.

In effect, guidelines for specifications of waste tires are dictated by the availability and handling costs of the tires. The data in table V.1 and the recommendations of ASTM F393-74 provide reasonable guides as to the technical characteristics which must be taken into account for retreading or use as fuel.

Table V.1. Characteristics of rubber for use as a supplemental fuel[a]

A. BTU Content
   1. Pure rubber--approximately 18,000 BTU/lb.
   2. Shredded rubber tires--approximately 15,000 BTU/lb.

B. Trace Element Concentrations
   1. Sulfur--approximately 1 percent.
   2. Zinc oxide--approximately 2 percent.

C. Materials Handling Characteristics
   1. Shredded rubber has a tendency to bridge.
   2. Stringers from reinforcing material can tie up rotating equipment.
   3. Rubber chips had a tendency to compress and become caught in the stokers.
   4. The size and purity of the shredded rubber was critical to materials handling throughout the system.
      a. The normal size required was 1"x1"x1/4"
      b. The shredded rubber must be substantially free of metals--bead, belting, etc.

[a] R. H. Taggart, Jr., "Shredded Tires as an Auxiliary Fuel", available from the Author, General Motors Corporation, Environmental Activities Staff, Warren, Michigan.

V.1.c. Asphalt-Rubber

Another possible use is to combine crumb rubber from waste tires with asphalt cement to create asphalt-rubber. This substance is a relatively new product and can be used as a binder in road building. Extended pavement life has been achieved by the use of asphalt-rubber in chip seal applications. These applications act as stress absorbing membranes which reduce the rate of crack propagation from the old pavement surface to the new surfacing material (reflection cracking). In addition to its engineering advantages asphalt-rubber extends the use of asphalt cement. Some forecasts indicate that after 1985, asphalt shortages are likely to occur.

After shredding, the vulcanized rubber crumb from typical whole passenger tires will contain approximately the following composition:

	Whole Pass.	Radial Pass.
Acetone Extractables, percent	19	18
Ash (from ZnOxide, etc.), percent	5	5
Carbon Black, percent	30	32
Rubber Hydrocarbon, percent	46	46
Natural Rubber, percent	18	22

Truck tires would use similar construction to that of a passenger tire but compounding would be quite different. A typical whole truck tire compound is compared with the peel section of a truck tire shown below:

	Whole T&B	Peels (Tread)
Acetone Extractables, percent	12.5	16
Ash, percent	5.0	4
Carbon Black, percent	28.5	30
Rubber Hydrocarbon, percent	54.0	50
Natural Rubber, percent	33.0	27

Chemical composition of the rubber has only minimal effect on asphalt-rubber mixes where the rubber remains substantially undissolved in the asphalt but can have a marked effect on asphalt-rubber mixes where it is solubalized to a greater extent.

Many of the primary uses of asphalt rubber have been in pavement rehabilitation systems which act to reduce the occurrence of reflection cracks. The most widely used systems are asphalt-rubber chip seals (SAM--Stress Absorbing Membrane) and asphalt-rubber interlayers (SAMI--Stress Absorbing Membrane Interlayer). At present, design and construction of these two systems are nearly identical.

Asphalt-rubber binder systems have also been used in hot mixed dense and open graded asphalt concrete and as a fog or flush coat application on open graded mixtures. The use of asphalt-rubber for crack pouring and joint sealing is gaining popularity. Asphalt-rubber binders as membranes for bridge decks, for control of swelling clays and for pond liners have been used on a trial basis. Asphalt-rubber has been incorporated in more than 2000 lane-miles of roadway in Arizona.

One company which produces asphalt-rubber binder uses a mix containing 23 to 24 percent of scrap tire rubber, 70-72 percent of asphalt cement and 4.5 to 6.5 percent. Kerosene type solvents are added to the reacted asphalt-rubber to control the viscosity required for spraying. The asphalt-rubber is reacted between about 325 and 400 °F and applied at temperatures between about 290 to 325 °F. Specially designed asphalt distributors are utilized as reaction vessels. A diluted emulsified asphalt is applied to the surface of the old pavement prior to the spraying of the asphalt-rubber binder. Cover aggregate is applied immediately after placement of the asphalt-rubber binder.

A second producer utilizes slightly lower percentages of rubber. This rubber is a blend of 40 percent powdered reclaimed (i.e. devulcanized) and 60 percent ground vulcanized rubber scrap selected to have a minimum of 30 percent natural rubber content. Industrial scrap rubber is often used as a portion of this rubber. The primary size of the rubber is between the No. 30 and No. 50 sieves. Rubber extender oils are mixed with the asphalt cement prior to the introduction of the rubber into the asphalt. The asphalt-rubber is reacted between about 350 and 425 °F and applied within the same temperature range. Reaction vessels may be used for preparation of the binder. Conventional asphalt distributors are used to apply the binder. Tack coats are not used prior to placement of the asphalt-rubber binder on the pavement surface.

So far as guidelines for specifications are concerned, performance cannot now be unambiguously related to physical properties in a general fashion. Hence, very tight quality control on the material is essential; one firm reportedly uses the following procedure:

1. Sampling of Materials
    a. Locally available asphalt cements (several sources and grades)
    b. Granulated crumb rubber
    c. Cover aggregate (all Stress Absorbing Membrane and selected Stress Absorbing Membrane Interlayer treatments)
2. Testing of Materials
    a. Asphalt cements
        (1) Absolute viscosity, 60 °C (140 °F)

    - (2) Penetration, 25 °C (77 °F) and 4 °C (39.2 °F)
    - (3) Rostler analysis
- b. Granulated crumb rubber
    - (1) Sieve analysis
    - (2) Chemical analysis (portions of ASTM D297)
- c. Cover aggregate
    - (1) Sieve analysis
    - (2) Asphalt-rubber stripping (Arizona DoT Test 217)
- d. Asphalt-rubber mixture
    - (1) Torque-fork time-temperature-viscosity, 177 °C (350 °F)
    - (2) Modified absolute viscosity, 60 °C (140 °F)
    - (3) Elastic rebound, 25 °C (77 °F)
    - (4) Force ductility, 4 °C (39.2 °F) or lower temperatures

After completion of the above testing program, recommendations are made for each project relative to asphalt source and grade, rubber material and percentage, asphalt-rubber reaction time, final mixture viscosity, amount of diluent and spraying viscosity. In developing the preceding recommendations, a number of factors are considered which include type of membrane (SAM or SAMI), project climatic conditions and type and volume of traffic. On the project, asphalt-rubber samples are obtained from each distributer truck prior to spreading for viscosity determinations using a battery operated rotational type viscometer. From these viscosities, adjustments may be made when necessary to the asphalt-rubber mixture, i.e., changes in reaction time and/or asphalt, rubber and diluent content. Very detailed job records are now maintained for future review and use in comparing material properties to project performance.

Binder properties are dependent upon the type and quantity of asphalt cement, type and quantity of rubber, type and quantity of petroleum based additives, reaction temperatures and reaction time. Considerable long-term research armed at developing theoretical models and a better understanding of asphalt-rubber binder systems (including laboratory-field performance correlations) has been suggested by proponents of asphalt-rubber. This need arises since asphalt-rubber is a new binder system which does not respond to analysis by conventional tests associated with asphalt technology. Furthermore, the binder and the binder-aggregate system are both chemically and mechanically complex and far from being fully understood.

Key economic considerations are 1) the price which must be charged for the rubber to be used in the asphalt-rubber binder, and 2) the probable necessity for public entities, such as state roads agencies, to procure asphalt-rubber based road materials at a higher first cost then conventional competitors. NBS/ORM sponsored work on lid modifiers and the general results of an NBS/ORM state procurement practices study provide some insight regarding the second issue (see Publications List #'s 49-54 and 56). Rubber price will vary, but a cost of 14¢ to 16¢ per pound (1982) is likely.

The basic challenge for proponents of asphalt-rubber is to show conclusively that reductions in life cycle costs can be achieved by the development of materials, equipment, and/or techniques which provide a desired combination of first costs and performance life. For example, a new product may have a higher first cost while providing an extended performance life which results in a lower life cycle cost as compared to a standard product. Nevertheless, many state procurement codes require that contracts be let to the lowest first-cost-bidder whose product will meet the performance specifications.

Proponents point out that asphalt-rubber may provide an attractive economic alternative for construction, rehabilitation and maintenance of our nation's roadway network. Economic advantages stem from increased life and reduced thicknesses of pavement sections. In addition the material is attractive from an energy and resource recovery point of view. As of December, 1982 the U.S. Congress was considering legislation provide supplemental grants to states which would adopt and implement programs to require the use of substances or materials based on rubber derived from waste tires in projects for constructing, resurfacing, restoring, rehabilitating, maintaining or reconstructing routes of the Federal interstate highway system, including bridges, tunnels and overpasses.

V.2. Large Volume Wastes

Large volume wastes include industrial by-products for which large storage inventories exist. These wastes include such materials as:

- Sludges
- Residual sulfates and sulfur bearing wastes
- Slags
- Mining wastes
- Organic wastes

- Incinerator reuse

- Fly ash

As an example, in the case of fly ash, such as that produced by a coal-fired power plant, the U.S. produces about 75 million tons per year of which 18 to 20 million tons is recycled or reused. Hence, over 50 million tons goes into inventory annually. There are estimates that 300 million to one billion tons represents current total inventory.

Fossil-fuel fired energy generating facilities produce sludges, slags, fly ash, bottom ash and sulfur bearing wastes. Some organic wastes may also be produced. Studies carried out on behalf of the U.S. Department of Energy concluded that, if these wastes--especially fly ash--were declared hazardous under Federal environmental regulations, the cost of electricity to the consumer would increase by 12 to 15 percent. The additional burdens would be unevenly distributed geographically. Furthermore, insufficient hazardous waste treatment capacity to deal with this "new hazardous waste" existed. In addition, NBS/ORM realized that, if fly ash were to be declared a hazardous waste, the amount of fly ash which is currently recycled or reused--18 to 20 million tons annually--would probably fall to nearly zero.

Fortune Magazine (November 20, 1978) put the problem in plain terms:

> "Fly-ash and sludge contain a rich variety of heavy metals and assorted other chemicals, many of which are known to be carcinogenic or otherwise toxic. These materials can leach out and possibly endanger streams, flood-plains and sources of drinking water such as aquifers. Under provisions of the 1976 Resource Conservation and Recovery Act, it is likely that the U.S. Environmental Protection Agency will declare ash and sludge to be hazardous waste, ineligible either for sale or for disposal by conventional open dumping. No one knows what then is to become of them."

(As of March 1983, these wastes have not been declared hazardous; they are designated "Special" and await further action.) NBS/ORM initiated studies to characterize fly ash and other fossil fuel technology wastes. [The U.S. Department of Energy/Laramie Energy Technology Center (DOE/LETC) sponsored (and cooperated in) many of these efforts.]

V.2.a. Fly Ash

For this material NBS/ORM investigations fell into three main categories:

1) Physical and mineralogical test method development, characterization and production of standards. For example, the NBS Office of Standard Reference Materials

(OSRM) has issued fly ash SRMs having certified composition and characteristics. The NBS Center for Materials Science, with ORM support, developed programs for quantitative X-ray powder diffraction for characterization of the ash. (Details of NBS/ORM work in this area can be found in Publications List #67).

2) Chemical test method development and evaluation. For example, proposed extraction procedures for leaching potentially toxic substances from ash were tested. Sampling procedures and test samples were selected for a variety of ash (and other waste) sources. (See Appendix VI).

3) Potential uses for fly ash in terms of physical and chemical properties. Appendix IV provides these results. Briefly, a wide variety of civil engineering applications are possible, e.g., road base, grout, insulation, but primary use is limited by compositional variability, transport costs and lack of technical information regarding its performance in construction materials.

Because of the extreme compositional variability and the potential for regulatory prescription, individual guidelines for specifications could not be developed. But the test methods, standards and characterization carried out by NBS/ORM can certainly serve as a foundation for individual decisions concerning recovery, recycling and reuse of fly ash.

V.2.b. Sludges, Slags and Mineral Wastes

These materials, which are by-products of various industrial processes, tend to be "large-volume" wastes. Many of these wastes are classified as "Special" by the U.S. EPA for purposes of regulation under RCRA. Key issues for these materials are:

1) Possibility that these materials or some portion of them will be declared to be hazardous waste;

2) Markets which would allow the materials to be utilized, primarily in civil engineering applications, in an economically efficient manner.

Uses and markets for these materials are extremely diverse. For example, steelmaking slags fall into two major categories, viz., lime-silicate slags or phosphate slags. The former is used extensively in roadbuilding in Europe; limits concerning volumetric stability and guidelines for free calcium oxide and magnesium oxide have been proposed. High phosphate slag demand is good; specifications are agreed by buyer and seller.

Mining wastes are used in concrete, cement, bricks and lightweight aggregates. In the case of cement manufacture, unburned shale is used to supply the agrillaceous component of cement so that the waste requires an alumina content of 25-29 percent and non-oxide content of 5-10 percent for this use. On the other hand, if base construction for roads is to be the application, the key is durability under highly specific conditions, e.g., climate, construction method, traffic-patterns, etc. In brickmaking, the carbonaceous material in the shale contributes an energy saving component in the firing process. In one method (Surschiste) a 40 percent savings of energy can be netted. Many other examples could be produced.

Sludges, slags and mining wastes are extremely heterogeneous in composition, and physical properties of marketable products tend to be achieved by special blending of virgin and waste materials. Thus, NBS/ORM did not attempt to formulate a comprehensive research/characterization effort for these materials. Indeed, such an effort would have required resources far beyond those available. With regard to guidelines for specifications for these materials:

1) By-product must not be classified as a hazardous waste, i.e., the entire lot must be sampled in a statistically valid fashion and the lot must pass appropriate state and/or federal requirements as set forth in appropriate regulatory documents governing what shall be deemed a hazardous waste.

2) Appropriate physical and chemical tests to meet performance requirements have been formulated by many groups, e.g., ANSI, ASTM, Portland Cement Association, for many materials to be used in civil engineering. Thus, addition or substitution of waste materials must still provide a product which meets these requirements.

3) The addition or substitution of the waste material must in some way yield a product having better value for money spent, i.e., better, more durable, cheaper, more energy conserving, etc. In other words, the lifetime cost of the final product must be as good or better than the non-waste bearing product. In one case, ferro-alloy waste (fume powder-mainly ferrosilicon by-product consisting of small SiO_2 spheres) was shown to provide better stability and durability properties when added to certain cements. The issue then becomes one of supply and demand for this material such that the economics are acceptable to buyers and sellers.

V.3. Plastics

Recycling of plastics, which comprise about two to three percent by weight, of the MSW stream can conserve energy. In fact, over 80 percent of the energy required for the preparation of typical packaging products, including the energy of petroleum feedstocks, can be saved. But economic and technical constraints have prohibited recycling of plastics mixed within MSW.

In Europe and Japan, where the plastic content of the MSW stream is two to three times in the U.S., some reclamation of plastics from mixed MSW has been carried out. The most notable success is in Italy where low density polyethylene is salvaged from Roman MSW. This material is mixed with various quantities of virgin resin and rendered into plastic bags which are then issued to Roman householders for use as garbage sacks. In Japan, manual sorting of the trash is carried out in order to reclaim plastics; source separated plastics are also collected. These plastics are cleaned and separated (in a circulatory tank) into a light fraction, e.g., polyethylene, polypropylene and a heavy fraction, e.g., PVC, PVDC. These materials are then pelletized and used to make rods, pipes and some decorative objects.

By far, the most advantageous use of waste plastic is recycling (either in original form or another plastic form or even as feeds for oils or waxes) back into the plastics production process. Guidelines for specifications are quite clear in such cases. The waste resin must meet virtually the same criteria as virgin resin. Hence, closed system reclamation by procedures and primary users of plastics is widely practiced. At present, there seems little choice but to obtain source separated plastics if reclamation is to be economically and technically feasible.

Research is being performed to determine if mixed plastics or plastics in mixed wastes can be separated conveniently and economically. Nevertheless, specifications for reinsertion as resin are unlikely to be substantially altered. Hence, NBS/ORM undertook no direct research in this area. Note that if plastics mixed in MSW are burned to recovery energy, no special precautions are needed. The material contains high energy content per unit weight, burns cleanly and in view of the information contained in Appendix III is unlikely to be a major source of potentially hazardous emissions.

V.4. Landfill Gas

In a sanitary landfill, each day's solid waste is covered with dirt or clay. Natural processes then operate within the landfill; the organic material decomposes. The result is gas--consisting primarily of methane and carbon dioxide but also usually containing mercaptans. The generation of methane gas is considered a nuisance and a potential problem. In fact, to prevent the gas from migrating to nearby areas where it could form explosive mixtures, collection systems have been installed. The gas collected from these systems is often flared.

Two main options exist for the use of landfill gas. First, it can be used as it is collected at the landfill (low BTU)--about half methane and half carbon dioxide, with only some compression and removal of moisture. In this form it is presently being used to generate electricity and fire boilers for space heating and industrial processes. The other option is to remove carbon dioxide, resulting in gas which is richer in methane (high BTU). In this form, it can be injected directly into existing natural gas pipelines.

Landfill methane recovery systems now in operation employ both of these options.

The applicability of high BTU landfill gas processing depends on the size and configuration of the landfill, and the location and capacity of a utility company pipeline, as compared with the location and volume requirements of a potential low BTU customer. In order to optimize the efficiency and economics of a methane recovery system, the maximum possible amount of gas must be withdrawn from the landfill and sold to a customer who can accept the entire output. The utility company pipelines usually provide greater flexibility in this regard.

High BTU systems also provide the capability of shutting down for maintenance repair or other reasons without incurring penalties from the utility company, since their line capacity has the capability of making up this lack of supply. On the other hand, a commercial low BTU customer who has relinquished his normal natural gas supply in favor of low BTU landfill gas may be severely impacted by even a short-term shutdown, unless he has a guaranteed supply of alternate fuel.

Another advantage provided by high BTU facilities is the potential for additional markets for carbon dioxide and liquid condensate by-products, which can enhance the economics of such a facility.

Although both high BTU and low BTU facilities must deal with the same general characteristics of landfill gas, a decision to go to a high BTU system takes the processing step totally out of the solid waste industry and places it firmly in the gas processing industry, requiring thorough knowledge of all available processes to handle a wider variety of landfill gas components and the problems associated with removing them from the gas stream.

Slotted pipes, embedded in gravel and connected to vacuum pumps or compressors, are used to collect methane from within a landfill. Processing facilities are on-site or nearby. Gas collected from the central portions of the landfill is normally rich in methane, usually about 50 percent. Gas withdrawn near the perimeter, however, sometimes contains too much air to be processed economically. If necessary, this gas is collected to prevent migration into nearby areas, and is usually burned off with a flare system. Thus, a landfill project may have two separate gas collection systems, a central one for energy production, and a perimeter system to prevent gas migration.

A number of factors enter into the decision of a community in considering a gas recovery system for its sanitary landfill and there are no hard and fast rules. The age, size, moisture, average depth and tons in place are key factors. Equally important are the potential end uses of the gas. Methane recovery probably is not feasible if the landfill is less than 30 to 40 feet deep, on the average. To obtain gas that can be used "as is", at least a million tons of solid waste should be in place. For long-term economical pipeline quality methane production, even more refuse should be in place, probably two or three million tons.

Composition of landfill gas varies from site to site and within individual sites. For those wishing to obtain and market economical quantities of high BTU gas, the guideline for specification is quite simple: the product must be of the same purity and energy content (1000 BTU/SCF) as that of nearly pure methane, i.e., pipeline quality.

In the case of low or medium BTU gas, specifications must be agreed between individual buyers and sellers based on need and economics. For example, the Ascon Landfill in Southern California produces gas with an average higher heating value of 530 BTU/SCF. A nearby oil refinery agreed to purchase this gas for daily use; gas pressure, moisture and heat value were specified as well as types and maximum tolerable content of contaminants.

In view of the market requirements for specifications for landfill gas and the highly site-specific nature of the gas, NBS/ORM conducted no direct research on this gas. The guidelines for specifications are either "pipeline quality" or set individually.

V.5. Compost

Non-toxic wastes can be converted to compost products by natural or accelerated processes. The problem in the U.S. has been lack of a steady market for the material. One of the causes of concern is that using compost created from consumer wastes indeed may inadvertently contain toxins. Thus, the use of this compost on food bearing cropland must be carefully monitored. Furthermore, the U.S. has rarely required large steady applications of the nutrients available in most composts based on consumer wastes.

NBS/ORM had virtually no involvement with any aspect of composting. One activity which was undertaken consisted of review of several proposals for EDA funding concerning methods to create and characterize compost from various sources. The only other activity was the analysis of some compost samples supplied by the U.S. Department of Agriculture (USDA). The USDA wished to know if a specific product of accelerated composting of municipal waste through bacterial action was able to pass the EPA extraction procedure test for toxicity.

This material was produced by means of the following process:

> Shredded MSW was inoculated with a substance that expedites the breakdown of all components in the waste. (Although toxic and hazardous materials are not knowingly handled in the system, small amounts of such materials supposedly can be introduced into the process without materially affecting the plant or end-product.) The shredded and inoculated waste was then conveyed to the composting area where it was windrowed in

a closed building on a concrete floor where biological activity, accelerated by the inoculant, breaks down the waste. The bacterial action is aerobic, which prevents the formation of odor forming gasses and generates great quantities of heat. Temperatures in the composting piles were allowed to reach approximately 170 °F long enough to destroy pathogenic bacteria. Incidental to the aerobic breakdown is the resulting structural change in glass (powdering), metal (oxidation), and plastic and rubber (acid, bacterial and heat reaction).

Each of the composting piles was numbered and readings of temperature and moisture content were taken at six-hour intervals. After about three days the pile was "turned" and repiled. The "turning" of the pile in this manner promotes aeration and with controlled addition of moisture the bacterial decomposition cycle is reactivated. After about four turning cycles over a period of fourteen to twenty days, the material reaches a black humus-like state and is stabilized.

The converted waste was then transferred from the piles by conveyor to a grinder or hammermill where it was reground to eliminate course material. The reground product was screened to insure full elimination of all coarse particles and finally fed into bulk storage or bagging equipment for marketing. The screening process rejected about 15 percent of the material as too coarse, but the rejected material was conveyed to blend with incoming material and reprocessed.

Samples of this material all passed the Ep toxicity test, i.e., would not be classified as hazardous under provisions of Subtitle C of RCRA. These results were conveyed to USDA. Apparently, this compost is a satisfactory soil conditioner, but NBS/ORM did no further tests on it.

Passage of an accepted toxicity test is the only guideline for specification which can be applied generally to compost created from waste. Markets for compost are highly localized, nutrient requirements for various agricultural or botannical cultivation processes vary considerably from place to place. Thus, if the prospective purveyor of compost derived from consumer waste can show that the material is not toxic, conventional market economics will determine if composting is an efficient means to reclaim some value from the waste.

Some idea of the costs of producing compost from MSW can be obtained using data quoted by J. Kass (Stock Market Magazine, September 1980). According to Kass, a plant capable of processing 76,500 tons per year of MSW would cost $4.5 million and would produce 53,500 tons per year of over 15 years, and if operating and maintenance costs were $17 per ton, then the cost to treat one ton of MSW after its arrival at the facility is about $20. If all 53,500 tons of product could be sold, the break-even price would be about $29 per ton of copost FOB the facility. These figures assume public ownership of the plant, i.e., no taxes. Presumably, a statistically valid sampling procedure would be combined with frequent testing to prove that all batches of product pass an accepted toxicity test and contain the mix and quantity of nutrients required by the customer.

VI. NBS/ORM AND THE RECYCLING OF INDUSTRIAL WASTES

NBS/ORM was concerned with increasing the possibilities for recovery, recycling and reuse of all materials which were destined for waste. With regard to industrial wastes, e.g., scrap metals, rubber, textiles, NBS/ORM attempted to develop methodologies which could lead to increased recycling on an economically sound basis. The work conducted by the State of Michigan on behalf of NBS/ORM by Lehigh University on behalf of EDA and by NBS/ORM directly provides some examples of these efforts. (See Sections V and VIII for details of these projects).

The National Association of Recycling Industries (NARI) has developed (and continually updates) guidelines for specifications for such items as non-ferrous scrap metals, rubber and textiles; as noted, the Institute for Scrap Iron and Steel does the same for ferrous metals. Therefore, NBS/ORM chose not to use its limited resources to try to perform direct studies of these materials. In effect, valid guidelines for specifications exist and are subject to constant review and revision.

With respect to the mandates of section 5003 of RCRA regarding market promotion and identification of barriers to recycling as applied to industrial discards, NBS/ORM worked directly with the steel industry and the leather and tanning industry. In this latter case, two recovery technologies were identified and an outline for cost effective research and development of these technologies was provided. The methodology developed in the Michigan/NBS/ORM study (see Section VIII) can be used to assess economic actions required to implement the options and to predict the likely outcome of such actions.

This approach, provided by NBS/ORM, can be replicated with other business and industry sectors. Small businesses would seem to be excellent candidates. NBS/ORM developed a pilot program plan which was meant to:

1) assist in reducing regional economic impact of federal hazardous waste management regulations;

2) protect and enhance productivity in selected industrial and manufacturing operations;

3) prevent unnecessary reinvestment of private capital; and lastly,

4) create a public awareness of the economic development potential in conservation or recovery of materials destined for disposal.

This program could not be implemented prior to the close of FY 1982, however.

A suggestion was submitted by NBS/ORM to DoC to form a group consisting of state officials, NARI, ISIS and NBS/ORM personnel to create a "Clearinghouse" meant to provide appropriate bases for dealing with supply and demand problems associated with recyclables to be procured by governmental entities. The procurement studies sponsored by NBS/ORM were to serve as the foundation for the necessary negotiations.

With regard to barriers, NARI and ISIS have developed detailed arguments concerning impediments to the economics of recycling. These include differential freight rates, e.g., more costly for secondary goods, tax policy, export policy and market fluctuations exceeding "normal" cycles. As these impediments are directly concerned with legislative and regulatory prerogatives. NBS/ORM did not deal with these issues directly. However, NBS/ORM personnel provided resource information to DoC policy decision makers on all of these issues. NBS/ORM personnel maintained contact with the major industrial recycling representatives, e.g., NARI, ISIS, American Paper Institute, individual firms, throughout the lifetime of NBS/ORM.

VII. PROCUREMENT PRACTICES RELATING TO ITEMS CONTAINING RECOVERED MATERIALS

VII.1. Legislative Mandate

Section 5002 states in part that:

"the Secretary shall also, to the extent feasible, provide such information as may be necessary to assist Federal agencies with procurement of items containing recovered materials."

VII.2. State Procurement Study

In order to fulfill this requirement and also to encourage greater commercialization of proven resource recovery technology as required by Section 5001, NBS/ORM initiated investigations of federal and state level procurement practices relating to products containing recovered materials. Clearly, increased procurement of such products would increase markets for recovered materials. Seven states, Colorado, Florida, Michigan, Minnesota, New Jersey, New York and Washington as well as the National Association of State Purchasing Officials (NASPO) cooperated with NBS/ORM by agreeing to:

1) Survey and report on state statutes pertaining to the procurement of products containing recovered materials.

2) Report on past, current or future programs and other state activities related to the procurement of products containing recovered materials.

3) Identify and report any legal, institutional, procedural, economic, or technical barriers to the state procurement of products with recovered materials.

4) Identify and report on any successful or unsuccessful attempts to procure products with recovered materials. This compilation to include those initiated by state solicitation or offerings by suppliers and manufacturers.

5) Provide a listing of the state's top ten products purchased based on volume and/or dollar value. This list was to include an cooperative purchases for local governmental, special districts or agencies.

6) Provide a listing, based on the best knowledge and experience in the state, or products that are most amenable to the inclusion of recovered materials.

7) For the list of products selected for item 6, provide all pertinent specifications, test methods, performance criteria and other information related to the procurement of each product.

The results of this study can be found by reference to ORM Publication List #'s 49-54 and 56. What follows was taken from the summary of the results: Responses to the several components of the project work statement were indictive of three important conclusions: 1) that the state purchasing offices appreciate the need to expand purchases of recycled products and reduce solid waste; 2) that the principal barriers to accomplishing this are lack of suitable standards, specifications, and price/performance criteria for individual materials; and 3) that there is need for a continuing means of interstate communication to focus attention inspire cooperation, and transmit experiences.

The validity and practicality of these conclusions could be tested by experiments involving all states working in a few selected product areas. Acceptability of recycling as a concept is likely to be affected in a positive way by growing economic considerations. This is already noticeable in the case of waste lubricating oils, as evidenced by visits during March 1981, of more than 100 purchasing, energy, and other administrators and officials from 47 states to the new re-refining plant being operated by the state of North Carolina. Traditionally, the United States has recovered some 20 percent of its waste paper for production of additional paper. In Germany, the figure exceeds 30 percent, and Japan imports certain grades of waste paper for this purpose. Declining highway revenues are spurring states to use more reclaimed materials in road construction and maintenance. These and other examples of the effect of economic factors suggest that in terms of procurement, perhaps the substantive aspects of recycling are only beginning to get underway.

Collectively, the purchasing programs of the fifty states have extension capacity for new and progressive ideas. But unfortunately, there is no mechanism or system available for stimulating, assembling, organizing, disseminating and exchanging these ideas. If the problems pertaining to the purchase of recycled products were identified and articulated in a manner to challenge state purchasing programs, and if an effective information exchange could be established, it could be expected that workable solutions would be forthcoming to the extent they are available. This broad-based, unique resource for innovation needs to be instituted and utilized to its full advantage.

Finally, there are supplementary ways by which NASPO might conduce to more buying and use of recycled products. An established information exchange would strengthen the success potential or related endeavors in which NASPO engages with other professional organizations, including current programs with ASTM (American Society for Testing and Materials) and NIGP (National Institute for Governmental Purchasing). And the Association could supply additional motivational support by institutional means such as consideration by its Executive Committee of formal endorsement of the concept, or a resolution to this purpose presented to the full membership for adoption at its annual conference.

If the purchasing knowledge and resources of the states are to be applied to the manifold questions inherent in the buying of recycled products, NASPO recommends that it be done by means of a program under the aegis and direction of the Council of State Governments.

One way in which such a program could test, and demonstrate, its effectiveness would be by assigning selected product areas to diffferent groups of states. Thus, one group could focus on the policies and problems associated with the purchase of rebuilt and remanufactured items. Another group could work in the field of recovered papers. A third group could concentrate on the entire spectrum of energy resource items, including the extended use or reclamation of oils. Among additional areas of examination could be the recycling of highway construction materials, and the in-house reconditioning of various kinds of equipment (office, transportation, furniture, etc.).

The program would require experimentation, and as appropriate, a trial and error approach. Test procurements would be made. Experiences would be analyzed, summarized, and disseminated to all of the states and to numerous interested parties. The Council of State Governments would exercise coordination in providing a policy or oversight component, and in securing the active participation of the industrial sector, local governments, trade associations, and of standards and specifications groups such as the American Society for Testing and Materials and the American National Standards Institute. The cooperation and assistance of a number of Federal agencies would also be needed.

Benefits from such a program, properly managed, would be many and varied, including gains which would be considered both short-term and long-term, primary and secondary, practical and theoretical. In addition to reduction of solid waste would be, for example, the fostering or the achievement of:

- A deeper understanding of the need for recycling.
- More clearly defined and usable standards and specifications.
- More complete and reliable information from manufacturers.
- Increased realization of savings through use of recycled items.
- More serviceable product labeling.
- A greater commitment by purchasing to the acquisition of recycled products.
- More explicit performance criteria for comparing recycled and virgin products.

- A better ability to calculate "social" cost benefits in evaluating bids.
- More artful drafting of Invitations for Bids.
- Added acceptability of recycled articles on the part of program agencies.
- Improved testing and evaluation capabilities of the individual states.
- A larger market for recycled products.
- More widely disseminated information among the purchasing community as to availability of recycled commodities.
- A better identification of problems capable of solution; of those not so amenable; and of alternatives.
- The inception of an ongoing public purchasing information exchange system.
- Increased conservation of public funds.

NBS/ORM commissioned two follow-up activities once these results were in hand:

VII.3. Development and Test of a Mathematical Tool Meant To Aid Purchasing Agents in the Analysis of Bids, i.e., a Bid Modifier, in Order that Recyclable Materials Might Be Purchased More Often

With respect to the bid modifier, a method was sought which would be designed to adjust bids received for a commodity to incorporate the estimated disposal costs of the commodity. A factor called the Purchasing Adjustment for Recycling (PAR) was developed based on the examination of the following factors: 1) the two most common disposal systems (landfilling, and incineration), 2) the data from a literature search, 3) a simulation of the bid/award process using prior purchasing records, and 4) discussions with purchasing personnel about the problems and attitudes that could affect the use of a PAR factor in bid evaluation.

While the PAR factor might well identify disposal costs, these costs usually were not sufficiently large to change the buyer's decision regarding the choice of which product to purchase. The buyer neither expected to actually pay the true costs of disposal, nor was he interested in revising the specifications (principally the style of the product) in order to purchase a recycled or recyclable product.

The PAR function might find an application as an educational tool for requisitioners and others in the logistics cycle who prepare the original specification or requirements for goods. If these originators of product purchases were better able to recognize the economic, social, and inflationary values of non-recyclables, progress towards the purchase of recycled and recyclable materials might be hastened. (See Publications List #74 for full details)

VII.4. Compilation and Issuance of a National Recycling Directory

The main purpose of the National Recycling Directory (Publications List #60) is to encourage recycling and the manufacturing of products made from recycled or recovered materials. This directory can be used to assist individuals, organizations, government, businesses, and institutions in their recycling efforts by providing information on markets for secondary materials. Federal, state and local governments should find the directory useful in their efforts to procure products made from recycled materials. Scrap processors and dealers can use it to aid in locating the closest or most suitable market for their materials. Community and other non-profit recycling programs will be assisted in locating the best markets for their recovered materials.

The companies listed in the directory manufacture products which contain some recycled or recovered material. The directory consists of separate sections for the types of materials used. The seven categories of materials are glass, ferrous metals, non-ferrous metals, paper, plastic, rubber, and textiles. Within each section, the states are listed in alphabetical order. The companies are listed in alphabetical order under the state in which they are located.

The listings do not include those companies which are exclusively dealer/processors, tire retreaders, energy recovery facilities, or are involved in the recovery of used oils, solvents, or chemical wastes. The directory has become very popular with those engaged in all forms of recycling. National publicity has resulted in a strong demand for the directory. An updated version was released in early 1983.

VIII. CHALLENGES POSED BY THE NEED TO DEAL WITH HAZARDOUS WASTES

During the lifetime of NBS/ORM (1976-1982), issues associated with the disposition of potentially hazardous wastes became a major public policy focus in the U.S. Therefore, other Federal agencies who were involved with measurement aspects of the hazardous waste problem sought the aid of NBS. These agencies included EPA, DoD, DoE and DoT. In addition, NBS/ORM had directly mandated responsibilities to investigate the possibilities, opportunities, and barriers to recycling of hazardous wastes. Thus, NBS/ORM became involved with many of the challenges posed by the need to deal with hazardous wastes. This Section will summarize NBS/ORM activities and contributions concerning hazardous wastes. Hence, efforts associated with Sections 5002, 5003, and 5004 of RCRA are included here in Section VIII of this report.

Production and use of many commercial items in the U.S. economy create a residual amount of material to be discarded. Under current U.S. law, when these discards are reactive, corrosive, ignitable, infectious, radioactive or toxic, they are termed "hazardous wastes." Under terms of the Resource Conservation and Recovery Act, as amended (RCRA) (P.L. 94-580; P.L. 96-482), hazardous wastes are to be monitored from creation through final disposal, i.e., from cradle-to-grave. In addition, so-called "Superfund" legislation provides for funding--largely through a tax on hazardous waste generators--to remedy threatened or actual environmental and/or health insults posed by abandoned hazardous waste sites.

A reasonable goal would be to achieve an economically and environmentally acceptable approach to meeting the challenges posed by existing, proposed and defunct facilities meant to deal with hazardous wastes. The magnitude of the problem has been investigated by the U.S. Environmental Protection Agency (EPA): Approximately 55-60 million metric tons of hazardous wastes are generated annually or about two tons every second of every day. In addition, EPA estimates that there are several thousand abandoned sites into which hazardous wastes were placed at one time or another.

Hazardous wastes pose challenges in three major areas:

- Technical evaluation, i.e., definition and measurement of the exposure of humans, ecosystems and livestock to potentially harmful effects of hazardous wastes.

- Economic evaluation, i.e., definition and estimation of the economic effects of various levels of control which might be imposed on generators, disposers, and recyclers of hazardous wastes. In addition, potential economic effects on other societal elements affected by the existence of hazardous wastes must be considered, e.g., the perceived value of a home when a previously unknown abandoned dump is found in the vicinity.

- Institutional responses, i.e., the reaction of a population which is in the vicinity of an abandoned, existing or proposed site. Here social and psychological factors may enter into consideration--and usually do. Often legal interpretation is sought. The question of who is liable for real or potential or imagined insult becomes of key importance in such instances. Next, the issue of what is the extent--in both dollars and time--of such liability is then of paramount importance to the parties of interest.

This section will deal primarily with technical approaches which will lead to a firm foundation for economic and institutional decisions. The goal will be to stimulate appropriate research and development of test methods, specifications, and practices relating to discarded materials destined for disposal. The object is to outline an approach to a measurement foundation which will allow for disposal of such discards in a technically, economically and institutionally acceptable fashion. Within the resources available, NBS/ORM attempted to develop a unified approach to fulfill the mandates of sub-title E of RCRA as applicable to hazardous waste.

In order to arrive at such an approach, background information on legislative and regulatory policy in the U.S. and other industrialized nations needs to be enumerated so that the parties of interest and their respective roles can be defined. Then a brief summary of conditions existing currently will be provided in order to identify specific challenges. Next, a framework for dealing with specific technical challenges can be postulated.

VIII.1. Background

Almost all industrialized nations have exercised a degree of control over hazardous wastes by means of national legislation and/or regulation overseen by a national agency. There is no particular uniformity to legislation defining hazardous wastes, but typically a set of substances is subjected to special rules. This list takes into account the properties of the waste which may produce specific effects. However, there is no uniform definition as to what it is that the waste must have a negative effect upon in order to be labelled "hazardous," i.e., the problem is not clearly defined. Still, Belgium, Denmark, West Germany, France, the Netherlands, Sweden and the United States have compiled lists of presumably objectionable wastes. Of all countries, only the U.S. deals with wastes which might pose a threat if improperly managed.

All of the laws and rules can be divided into two categories:

- Prescription of a certain conduct

- Prohibition of a certain conduct

For example, the West German statute of 1977 states that "waste shall be disposed of in such a way that the well-being of the community is not impaired." Next, a list of situations which must be avoided is provided. The 1975 French law is similar.

In all cases, the duty to maintain records and, in certain cases, to notify responsible authorities, plays a pivotal role in the legal régime for hazardous waste management, where documentation and information are essential for effective monitoring and control. Indeed, the U.S. EPA flatly states that:

> "Cradle-to-grave control via manifests and reporting is the keystone of the program; only permitted sites may receive hazardous wastes. EPA anticipates 25,000 permit applications nationally."

A license or permit for waste treatment facilities is required in all countries. Permit applications require information regarding types and quantities of waste involved, technical capabilities, safety precautions and methods and sites for disposal. In addition, many states in the U.S. have separate laws and regulations governing hazardous waste treatment; these must be at least as stringent as the Federal laws and regulations. Furthermore, state-to-state "consistency" is required by Federal law.

In summary, the following similarities exist between the various legal entities for the transport, treatment and disposal of hazardous waste within industrialized countries:

- Hazardous waste must not be abandoned;

- Hazardous waste belongs to the generator;

- The generator is responsible for ensuring safe disposal of hazardous waste;

- The "polluter pays" principle applies to all hazardous waste generated, abandoned, transported, treated and/or disposed of;

- Detailed records concerning such things as quantities, types, methods of treatment, and disposal sites must be maintained during all phases of hazardous waste operations; reports must be furnished where required;

- Hazardous waste must be handled separately from other waste;

- Whether hazardous waste is treated on-site or off, it must be done under close supervision and by competent personnel applying environmentally safe methods;

- Hazardous waste which is treated off-site must be treated installations which are either licensed or operated by the authorities.

Obviously, the industrialized world is concerned about the challenges posed by the existence of hazardous or potentially hazardous discards, but no one has yet defined the problem or a unified program to deal with all aspects of the situation arising from the existence of such wastes. In an effort to do so, at least two major cooperative studies have been undertaken in which the U.S. was an official participant:

- NATO Committee on the Challenges of Modern Society study entitled "Disposal of Hazardous Wastes" begun in September 1973 and completed in April 1981
- Organization for Economic Cooperation and Development (OECD) study entitled "The Control of Hazardous Waste in Selected Member Countries," begun in 1980 and still under way. NBS/ORM participated directly through 1982. (See Section VIII (14) for details.)

The NATO study concluded that there are ten major priority topics or challenges which needed attention:

- Approaches to the Definition and Classification of Hazardous Wastes;
- Control Mechanisms for Hazardous Waste Disposal;
- Siting of New Hazardous Waste Disposal Facilities;
- Transboundary Disposal of Hazardous Wastes;
- Improvement and Harmonization of Hazardous Waste Disposal Quality in NATO Countries;
- Relationship between Hazardous Waste Disposal and Environmental Protection in General;
- Problem of Abandoned Sites;
- Role of Recycling and Resource Recovery in the Area of Hazardous Wastes;
- Financial Responsibility and Liability for Hazardous Waste Disposal Facilities;
- Need for Research and Technology Development.

The NATO project participants concluded that--from the point of view of environmental amenity--the desired management options ranked in order of desirability are:

- Reduce generation of hazardous waste;
- Separate out and concentrate the waste;

- Utilize the waste either directly or via recycling;
- Detoxify and neutralize the waste;
- Destroy in special incinerators;
- Dispose in "secure" landfill.

Indeed, this priority listing was one basis for current U.S. regulations concerning hazardous waste disposal.

Central to all regulations is the so-called "polluter pays" principle, i.e., the agency responsible for generating the waste must pay for its eternal care to assure that no environmental insult occurs. Thus, the liability aspects in theoretical legal form are defined.

The NATO study states bluntly that:

> "Liability requirements are necessary because of the potential for damage to people and property from hazardous waste management operations, as indicated by actual damage cases and the very nature of hazardous wastes. If the facility owner has insufficient financial resources to pay for damages, private parties or government may be forced to bear the costs. Liability protection is necessary and should be provided for both sudden occurrences, such as fires and explosions, and for non-sudden occurrences, such as slow migration of toxic constituents from hazardous waste landfills or surface impoundments."

In the U.S., bonds and insurance provisions against the potential for damage as a result of hazardous waste treatment facilities were required through the regulatory mechanism. But as stated in the NATO study, the lack of information and experience precludes a decision in favor of or against specific models for financial responsibility and liability. Thus, most countries still try to determine liability through traditional channels in the framework of normal civil law.

The OECD study is focused on four major aspects of the control of hazardous wastes:

- "Problem" or abandoned sites;
- The transfrontier transport of hazardous wastes;
- The private and public costs of complying with the provisions of hazardous waste regulations, and of administering them;
- The insurance and assurance problems raised by such regulations.

The OECD study began recently (1980), and only the abandoned site problem has been dealt with in any depth to date. A symposium was held at which experts from the OECD countries reached the following general conclusions:

- The awareness of, problem waste sites is relatively new in most countries and scientific and government institutions are experiencing considerable difficulty in meeting the challenge.

- The location and discovery of many problem waste sites without the institutional capability to deal with the resultant problems has caused significant public anxiety.

- Actual and environmental and public health impacts resulting from problem waste sites is in general either very poorly understood or misunderstood. The scientific foundation on which particularly health impact assessments is based is weak. As a result development of such health impact measurements will probably be some time in development.

- Environmental and health impacts are complex and far reaching; remedial and countermeasures are uncertain in the long term and often exceedingly expensive. The most practical and effective solution lies in avoidance of such problems before they occur, by minimizing the placement of "problem wastes" in the ground and by proper engineering and control of those land disposal sites which are absolutely necessary.

The foregoing background material is meant to help define the general legal, regulatory and institutional challenges posed by the need to deal with hazardous wastes. In what follows, the situation with respect to the U.S. generation of hazardous waste will be outlined.

According to EPA, in 1979 seven industry sectors generated 28.1 million tons--or about half--of all U.S. hazardous wastes. These sectors include:

- Primary metals--8.3 million tons per year.

- Organic chemicals--6.7 million tons per year.

- Electroplating--5.3 million tons per year.

- Inorganic chemicals--3.4 million tons per year.

- Petroleum refining--1.8 million tons per year.

- Textiles--1.8 million tons per year.

- Rubber and plastics--0.8 million tons per year.

Over 65 percent of hazardous wastes are generated in ten states: Texas, Ohio, Pennsylvania, Louisiana, Michigan, Indiana, Illinois, Tennessee, West Virginia and California.

The total number of generators of hazardous waste in the U.S. is estimated by EPA to be 760,000. Of these:

- 695,000 generators produce less than 1000 kg per month for a total of 600,000 tons per year;
- 563,000 generators produce less than 100 kg per month for a total of 138,000 tons per year; and
- 40,000 generators produce more than 5000 kg per month for a total of 22 tons per year.

Obviously, the impact of hazardous waste management regulations cannot be divided evenly among all of the disparate generators. Some of the factors leading to differences in impact include:

- Nature of processes generating regulated wastes, including correlations of the intensity of waste generation and relationships between relative value of product and the costs of waste management;
- Economy of scale factors: Above the "small generator" threshold, a number of regulatory parameters such as costs associated with financial responsibility, recordkeeping, increased storage, transportation, treatment, and disposal appear to favor larger over smaller operations;
- For similar industrial operations, newer plant facilities are likely to have an economic impact advantage over older facilities based on, but not limited to, improved process technologies and improved waste management technology available; and,
- Economic impact differentials between types and sizes of industries are likely to appear as relationships to overall market competitiveness, e.g., ability to pass on cost differentials of the hazardous waste regulations without significant loss of market.

According to the Illinois Environmental Protection Agency, approximately 25 percent of businesses in the State are likely to be adversely affected by Federal hazardous waste management regulations. Those industries most seriously impacted are foundries, small plating operations, and small plastic manufacturing companies. The costs of hazardous waste disposal to small process industries such as electroplaters preparing integrated circuit devices, and tanners, can be exceedingly large as compared to gross sales from business.

To compound the uncertainties faced by generators and disposers of hazardous wastes, some 30-35 states will probably obtain temporary authorization to regulate hazardous wastes and operate the RCRA programs independent of EPA. Note that EPA must operate the program in any state not gaining such temporary authorization. Ultimately, state programs must be equivalent--or more stringent--with respect to the Federal program, consistent with other state programs, and provide for "adequate enforcement."

Finally, local opposition to the establishment of waste management facilities is a major obstacle not only for hazardous waste management but for solid waste management in general. Such opposition has often blocked environmentally and economically sites.

Several states and a number of localities have imposed bans and restrictions on the movement of waste into their jurisdictions. Restrictions on the movement of hazardous waste have caused especially difficult problems--many of the specialized facilities equipped to handle certain hazardous wastes must serve large areas in order to be economically viable.

Assurance of improved management of waste and incorporation of public education and participation measures may affect public attitudes, but whether they will reduce opposition enough to permit all the well-justified sitings that are needed is uncertain.

VIII.2. Current Status in the U.S.

The situation within the United States today was created by the EPA efforts to compile regulations governing hazardous wastes from cradle-to-grave. A former Assistant Administrator of EPA declared the initial fruits of these efforts to be the "most complex set of regulations ever issued by any government at any time in history." The regulatory program includes:

- Identification of hazardous waste;
- Standards for generators and transporters of hazardous waste;
- Performance, design and operating requirements for facilities that treat, store or dispose of hazardous waste;
- A system for issuing permits to such facilities; and
- Guidelines describing conditions under which state governments can be authorized to carry out their own hazardous waste management programs.

Each of these general areas is buttressed by extremely detailed descriptions of characteristics, performance specifications, tests and trigger concentrations of pollutants which can result in a waste being classified as hazardous and the generator of that waste being held responsible--in perpetuity--for any possible damage the waste may cause.

Lists of proscribed substances were compiled by EPA using the RCRA definition of hazardous waste, i.e., a solid waste which may cause or significantly contribute to serious illness or death, or that poses a substantial threat to human health or the environment when improperly managed. In addition, EPA defined proper management of such wastes and detailed specific tests for ignitability, corrosivity, reactivity and toxicity. EPA also required all generators of such wastes to register in 1980.

During the period 1976-1981, environmental insult due to hazardous wastes occurred. The most notorious instance was at Love Canal near Niagara Falls, New York. The news media dealt with real and potential effects of hazardous wastes in great detail. Hence, public awareness of the problem was heightened and public aversion to risks due to exposure to hazardous wastes strongly increased. Indeed, public opposition has closed at least one site which formerly had valid state and Federal permits; this closing has been upheld by the courts on the basis of the presumed possibility of harm to the population which might be exposed to emanations from the site.

The current situation, as a result of the legal and regulatory actions since 1976, can be summarized for each of the three major components of the problem, viz, technical, economic and institutional:

Technical: Much of the effort of the past five years has been in reaction to EPA actions and proposals. For example, EPA proposed a test for hazardous waste based upon a model presuming a mixture of industrial and municipal wastes leaching from a landfill. Literally, thousands of hours of professional staff time have been spent investigating this one aspect of the regulations. The physical chemistry and kinetics of any leaching process are unknown to this day. Yet, on this issue, ASTM took the unusual policy step of testifying before Congress in opposition to this one test.

As another example, a waste substance was declared hazardous if after leaching, the concentration of the resulting leachate was 100 or more times that allowed for drinking water. Yet nothing was said about analytical uncertainty.

Economic: Great uncertainty exists in the minds of the generators of wastes designated as hazardous by EPA tests. Liability for actual or alleged damage is undefined; insurance is difficult or impossible to procure. Since EPA has claimed that about 90 percent of hazardous wastes in the U.S. are disposed of by environmentally unsound methods, the average cost and availability of disposal facilities has skyrocketed. Rumors exist that illegal dumping operations have occurred; the U.S. Congress held hearings on this possibility in 1981.

Since most large generators have traditionally dealt with hazardous wastes on-site, they are likely to continue to do so. In addition, because of potential--and undefined--liability issues, such generators are likely to resist having their disposal and treatment facilities utilized as a communal site. Thus, small generators will require permitted communal sites at an affordable cost. The alternatives are reduced profits, illegal actions or maybe even closure of the business.

Finally, many industries which produce relatively large volumes of waste which are not deemed hazardous under present law have encountered steeply rising disposal costs simply because they generate "industrial waste." Examples include foundry sands and ferro-alloy wastes. A final example is fly ash produced by the Nation's power industry. A Department of Energy study indicated that the average electricity bill for consumers would increase 10 to 15 percent if that ash were found to be a hazardous waste.

Hence, literally billions of dollars and the fate of a number of small businesses rest upon the need for technically accurate and legally equitable administration of the RCRA and Superfund legislation.

Institutional: The key actors are local and state government, the Federal establishment, generators, transporters, disposers, recyclers and the general public. At issue is the possibility of siting new facilities, monitoring existing facilities, and remedial action relating to abandoned sites. There appears to be no unified policy in this area. Unless a policy can be brought forward which is acceptable to the key actors, the courts are likely to make national policy via qualitative concepts as developed on a case-by-case basis under common law. In reaching decisions concerning risks under common law, courts usually rely on concepts of reasonable behavior, of duties and responsibilities to inform, of assumptions of risk that are borne by various parties and of contributory actions. Application of these concepts is constrained by common law precedents, procedural rules and rules concerning the admissibility of so-called competent evidence. Quantitative considerations of economic and technical data are likely to play a minor role in such instances.

With regard to hazardous waste regulatory efforts in the period 1976-1981, EPA apparently emphasized quantitative requirements in reaching decisions, e.g., a statement that such-and-such waste is hazardous if its concentration in a leachate exceeds "X" parts per million where "X" is defined to two or three significant figures. This emphasis on numbers to reach certain analytical outcomes has produced an apparent lack of credibility or acceptance with the public which wishes "no risk" and the regulated community which must abide by some regulatory framework that is supposed to be consistent while providing for a means of obtaining the desired environmental amenity at lowest possible cost.

Thus, the current situation can be described as confused: Technical efforts have been largely in reaction to regulatory proposals. With regard to economic issues, great uncertainty exists in the regulated community since liabilities are basically undefined. The public is faced with loss of property values as well as other risks. Institutional issues concern legal definitions and responses to regulatory actions at all levels of government. The simple fact is the parties of interest feel that no unified or consistent policy exist.

VIII.3. Specific Challenges--Options and Impacts

VIII.3.a. Approaches to a Definition and Classification of Hazardous Waste

During the past five years, the political and regulatory discussion has, to a large extent, focused on the question of what constitutes a hazardous waste. This discussion has not been completely fruitful, to the extent that an international consensus has not been achieved on this issue. The question has often been posed without indicating clearly the legal requirements which the definition and classification were required to satisfy. A frequent oversight is that the definition of hazardous wastes has to meet quite different criteria when one looks to the various elements of the overall disposal system. Requirements for the classification of hazardous wastes for transportation, disposal or treatment controls are likely to be stringent.

There are three basic approaches which can be taken towards the legal classification of hazardous waste: first, a pragmatic solution is achieved by describing the waste in a qualitative way, indicating type, origin and constituents of the waste; second, a more scientific approach defining hazardous wastes by certain characteristics usually involving standard testing procedures; and, thirdly, definition of the waste in association with concentration limits of harmful substances. In the latter case, the presence of certain listed hazardous components in a waste beyond a defined concentration makes a waste a hazardous waste.

All three approaches can be justified. The first one has the advantage that a legal system, based on that type of definition, can more easily be administered and enforced without too much bureaucratic difficulty. It also gives a certain flexibility to the waste disposal authorities in making qualitative judgments on individual waste disposal situations and, thus, in meeting practical needs. The effectiveness of this listing approach is essentially dependent on the legal system of individual governmental entities, in particular the flexibility to make case-by-case decisions by the controlling authorities to incorporate problematic wastes into the hazardous waste control system.

The other two approaches have the advantage of presenting a clear and accurate description of wastes, theoretically leaving no doubt for the waste generator and waste disposer about how to deal with the waste. These precise definitions imply a tight control and surveillance of the definitions and parameters which in practice may pose problems with respect to limited manpower, both on the part of waste generators and the controlling authorities.

Further evidence is required in order to decide which one or which combination of the three approaches is most appropriate to ensure proper hazardous waste disposal at minimum administrative costs. This question must not be isolated from the overall hazardous waste disposal system. The central objective of such systems is to dispose of the waste correctly, and this is less a problem of the definition of the waste than of actually applying disposal criteria and disposal opportunities. At present, there is no evidence in practice of a direct correlation between the quality of disposal and a high degree of accuracy in the legal definition of hazardous wastes expressed in terms of chemical composition, and concentrations of toxic substances.

Hence, sustained efforts aimed at providing a "better" or more "accurate" definition of hazardous waste are not likely to succeed on any objective basis. More important, such efforts are not likely to be satisfactory to the interested parties. Perhaps the only real-world definition of what constitutes a hazardous waste is that waste which some segment of the populace views as potentially harmful to themselves or to an ecosystem and about which they are willing to take action.

VIII.3.b. Identification of Possible Disposal Options Available at an Affordable Cost

Generators of potentially hazardous wastes have examined this issue in some detail as have "blue-ribbon" committees of scientific and technical personnel. For most wastes, disposal means thermal degradation or burial, i.e., incineration or disposal in or on land. Technologies to dispose of such wastes via other means are not often available although technologies exist to reduce the amount of such waste, e.g., wet air oxidation, simple neutralization and others. Still, final disposal is virtually certain to require "bury" or "burn" as the major means. There appears to be no way to avoid this conclusion. Technical efforts must deal with potential difficulties arising from land-based disposal methods and from incinerator operations--both on land and at sea. Of course, all abandoned hazardous waste sites are land based or landfills.

VIII.3.c. Development of an Equitable Level of Control System

Here, agreement between Federal and state and local governmental entities is essential. Basically, what is required is to evaluate--as quantitatively as possible--a regulatory stance embodying hazardous discard disposal via incineration or some form of landfill which embodies the concept of level of control. One goal of such an effort is to provide the state-to-state consistency required by law. Then agreement must be obtained from the regulated community and the public. (Note that transport of wastes to appropriate disposal sites is included here.)

VIII.3.d. Provision for a Valid Monitoring Scheme to Assure That Exposure to Potentially Harmful Constituents of the Waste is Minimized

A monitoring system agreeable to all parties of interest needs to be developed. Without such a system, no valid assessment of potential harm is possible. Hence, the courts may prescribe solutions which will be difficult to achieve using best available technology.

VIII.3.e. A Means to Evaluate Potential Harm

This challenge requires a means to relate what can be measured directly, e.g., chemical composition, chemical concentration to the probability that some adverse effect will be observed.

VIII.3.f. A Unified Means of Informing all Parties-of-Interest of Actions

Without some system of information transfer, the likelihood of siting a proposed facility, expanding disposal capacity or providing for rational remedial action in case of unanticipated potential harm to the environment, e.g., discovery of an abandoned landfill or a spill, is likely to be strongly diminished.

VIII.4. Technical Approaches to Specific Challenges

The technical community must provide basic information concerning improved technologies for reducing the burden of hazardous wastes via resource recovery, recycling and reuse of constituents destined for disposal. But, there will always be a need for disposal of potentially harmful substances. At present, incineration and land disposal appear to be the only economically feasible means to achieve final disposal. Indeed, any residues from an incinerator dealing with solid waste will need to be disposed of in or on the land. Naturally, if the oceans are re-opened to the disposal of certain constituents of wastes deemed compatible with the ocean environment, e.g., chlorinated wastes, then other possibilities will exist. However, under current international agreements and existing U.S. law, the oceans are closed to any such disposal options. Therefore, this section will deal only with land disposal and incineration.

1) Land disposal

Assume that there is an existing or proposed land-based site in which possibly hazardous discards have been (or will be) placed. The site can be a pit, pond, lagoon, landfill or land spread, deep-well injection, salt dome or encapsulated (fixed) deposit. Note that abandoned sites can be taken into account as well. In addition, airborne effluents and residuals from an incinerator can be included. Almost certainly, general questions which follow will have to be dealt with in some detail.

a) What is present?

This question requires that qualitative analysis for all constituents be carried out. Generators and disposers can, of course, check incoming shipments fairly accurately. In the case of old sites, some means of accurate qualitative analysis sensitive to very low levels of various constituents must be developed. Thus, sampling protocols and relatively rapid identification procedures are needed--which are affordable. Clearly, organizations such as ASTM will need to compare sampling protocols, develop and evaluate various test methods and agree on standards of comparison.

b) How much material is present or planned for the site?

Total amounts of potentially hazardous substances will be of interest to any local jurisdiction.

c) How long has the site been in its present location? Are records available?

This information is needed if an appropriate monitoring scheme for emanations from the site is to be developed.

d) What is in the vicinity of the site? Are its boundaries--in three dimensions--well defined?

Paths by which emanations from the site may migrate into ecosystems, e.g., via ground water, surface water, air, soil, etc., must be determined. Population density and land use data are also required.

e) Are constituents escaping from the site?

Soil characteristics need to be assessed, e.g., composition, permeability to the constituents at various depths, conductivity, pH and others. In the case of long-term or abandoned sites, baseline data are needed. Rainfall, rain pH and rain analyses are needed as well. Perhaps the appropriate leaching medium for any given site is the liquid which filters through a system of local soil subjected to having local rainwater poured over it. In fact, a total geological and hydrological study of the vicinity of the site is likely to be necessary. Again, standard practices, tests and data reporting protocols are required. In the absence of consistent methods, conflicting results are likely to occur leading to legal actions. Indeed, in one case, conflicting data due to different methodological approaches dealing with possible sources of contamination of groundwater lead to threats of litigation and finally a consent decree whereby the presumed generator will pay full costs of remedial actions and is subject to virtually constant monitoring by public agencies.

f) Determination of potential for harm.

- Quantitative characterization must be carried out in order to determine possibility of exposure of humans or ecosystems to the constituents of the site. The development of a measurement assurance program is required so that the results from complex and expensive tests such as GC/mass spectrography can be translated, on a controlled basis, to less complex and less expensive tests having similar precision and accuracy. Of course, a valid sampling technique is implied as well.

In this context, the question of guarding against or detecting concentrations above a certain datum becomes of interest. The datum may be set by regulatory action or the probability of adverse effects if the concentration exceeds some datum which may have been determined empirically. In any event, classical statistical considerations (nonparametric tolerance limits) can be used to determine how many samples must be investigated in order to determine some probability of finding a proportion of the total population below the datum. For example, for a probability of 99 percent that 99 percent of all possible tests will be below the largest concentration measured, some 459 separate analyses are required. Conversely, if four separate analyses (replicates) are performed, one can only be 70 percent certain that 70 percent of all possible tests will fall below the largest of the four concentration values measured.

Research is needed to determine the relationship of easily measured parameters, e.g., pH, to the potential for adverse effects. In any case, statistical uncertainties are likely to make "legally accurate" concentration determinations difficult to achieve.

o Kinetics of what is present in terms of local surroundings.

In this case, research is required to determine constituents and their concentrations, as they move in a specific ecosystem, by a variety of paths, as a function of time. This presents a monitoring problem, i.e., concentration as a function of distance and time to define increased exposure to the contents of the site.

If all of the needs described to this point were met, i.e., rapid, accurate qualitative and quantitative measurements of effluents from the site in a statistically valid fashion, the net result would be a determination of exposure to the contents of the site as well as a determination of who and what are exposed at a given level. No mistake should be made in thinking that obtaining these data is simple, straightforward or inexpensive in terms of professional talent, equipment and dollars. Yet, without these data, no valid statement concerning exposure levels can be made. With such data firmly in hand, the final technical challenge can be enumerated:

o Relationship between concentration of constituents and cumulative probability for adverse consequences. In simpler terms--effect.

This challenges requires that the exposure or dose experienced as a result of the hazardous waste facility via any path be related to observed instances of harm or the possibility of harm at some undefined future date. In the following discussion, assume that the exposure or dose occurs as a result of a hazardous waste facility. Further, assume that the exposure can be measured accurately and that the sampling procedure is statistically valid.

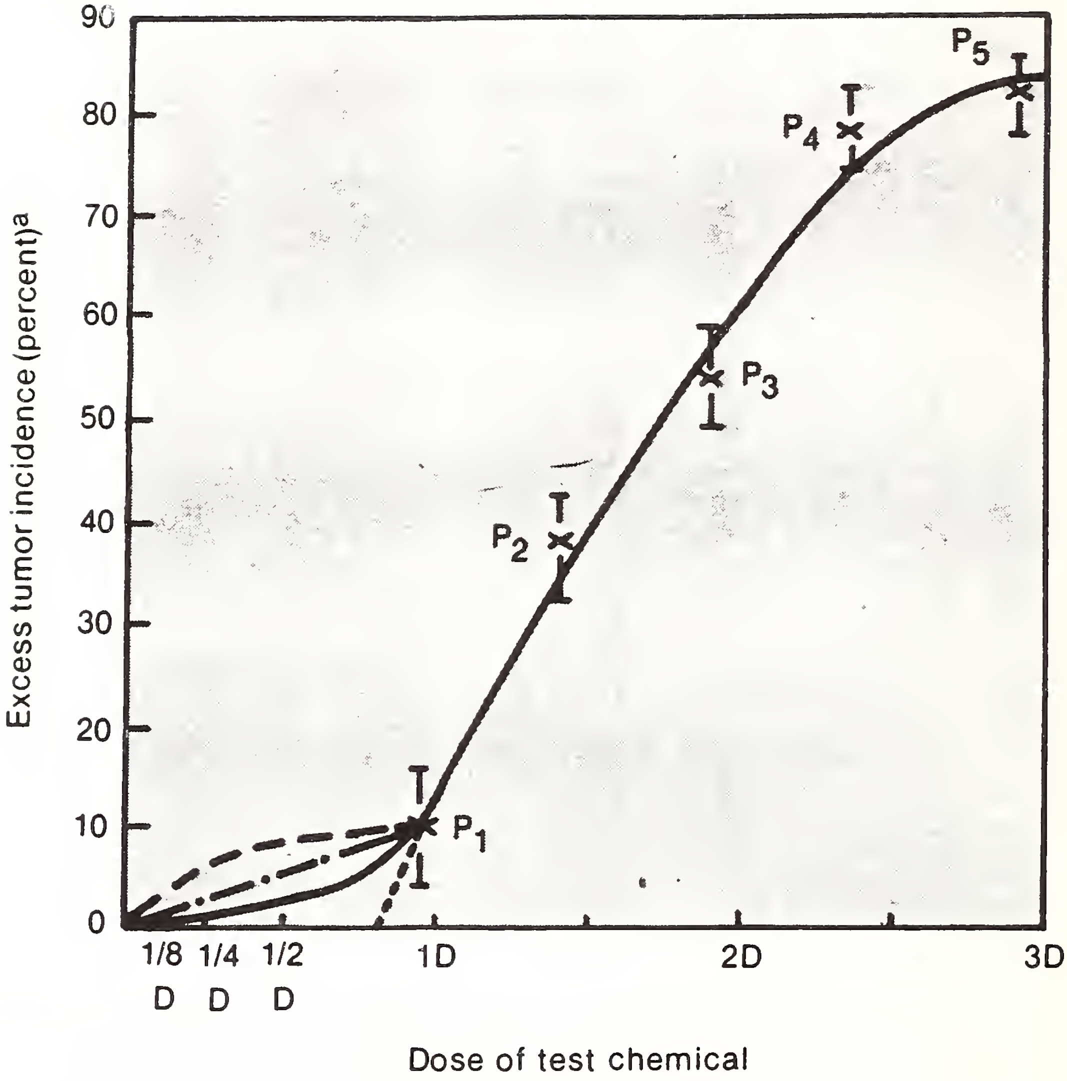
Plots of incidence of adverse effects in animals and humans as related to exposure or dosage always result in a sigmoidal or S-shaped dose-risk curve (see fig. VIII.1). Under the terms of the assumptions, zero dose means zero risk. But, the cumulative probability of risk as a function of very low doses or levels of exposure is nearly impossible to measure or to predict theoretically as indicated in figure VIII.1.

For example, the question of a dose threshold arises immediately. If a threshold exists, then there are exposure levels of certain substances, e.g., carcinogens, such that no matter how many animals are exposed, none will exhibit cancerous tumors. Leading authorities have stated flatly that resolution of the threshold question is not possible given the current state of scientific knowledge--even in a large-scale experiment involving several thousand animals per exposure level.

Next, if no threshold is assumed, i.e., one molecule of the substance has some finite--even if vanishingly small--probability of causing harm, the relationship of the exposure to risk level must be correctly known as the exposure approaches zero. Here two other uncertainties intervene: 1) What is the minimum detectable limit of concentration of the emanations from the site in the various paths and media via which the emanations can travel? 2) is there any valid mathematical statistical model for extrapolating from detectable levels to zero exposure?

Minimum detection limits in the so-called part-per-billion range, for certain organic and inorganic species have been reported. Such determinations--especially in heterogeneous mixtures and media--have wide ranges of uncertainty (large confidence intervals) and are exceedingly difficult to perform. (Note that one part-per-billion corresponds to about 600 trillion molecules of the substance under test.) Accurate measurements at low exposure levels are likely to be difficult and very expensive.

Consider now models for extrapolating from measurable exposure data to the risk at lower exposures. In one experiment, some 24,000 female mice were subjected to a known bladder and liver carcinogen in order to study dose responses down to a one-percent tumor incidence, i.e., the concentration of the carcinogen which would cause one mouse in 100 to develop liver or bladder tumors. Results of these tests were



[a]Excess tumor incidence (percent) is defined as:

$$\frac{\text{tumors in exposed population}}{\text{number of exposed population}} - \frac{\text{tumors in control population}}{\text{number of exposed population}} \times 100$$

——— a sigmoid dose-response curve; infralinear between O and P_1

—·—·— linear extrapolation

— — — supralinear extrapolation

------ line projected to a threshold

SOURCE: Office of Technology Assessment.

Figure VIII-1. A Stylized Dose-Response Curve and Some Extrapolated Curves.

not especially enlightening. For example, a linear extrapolation and a "Weibull model" which is a statistical probability distribution having a finite starting point for estimating life distributions as a function of exposure, were applied to the data.

For a one in a million risk ($P = 10^{-6}$) of liver cancer in the mice, an 0.045 part-per-billion dose of the carcinogen was predicted by the linear model; the Weibull model predicted a 4.5 part-per-billion dose for $P = 10^{-6}$ or an exposure of 100 times greater for the same risk.

The EPA Carcinogen Assessment Group has stated that:

> "There is no really solid scientific basis for any mathematical extrapolation model which relates carcinogen exposure to cancer risks at the extremely low level of concentration that must be dealt with in evaluating the environmental hazard."

With respect to the prediction of "time-to-tumor" data, there is no agreement between available models. Results are different, and certainty of prediction appears impossible at present.

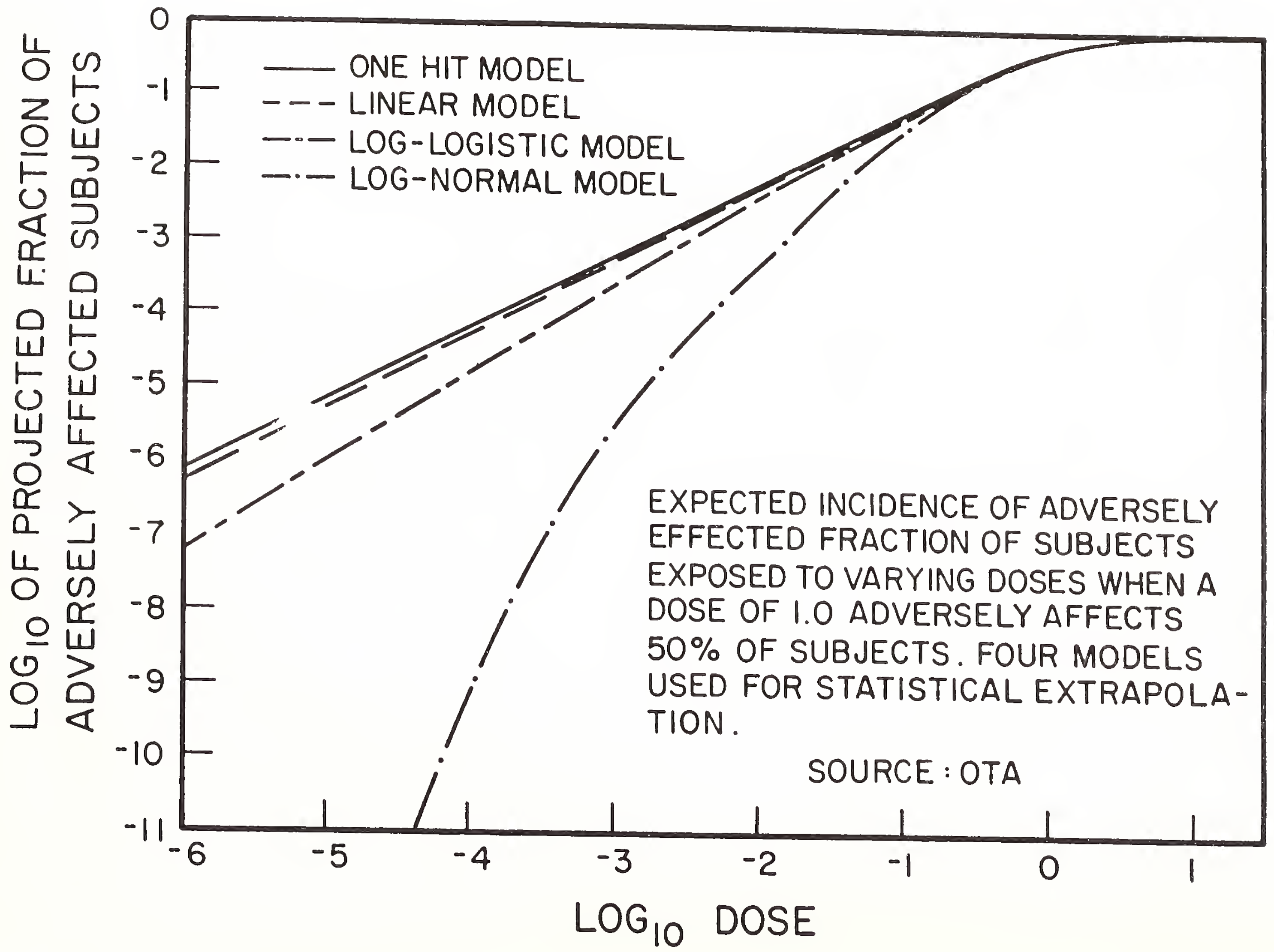
As stated by the Congressional Office of Technology Assessment:

> "The accuracy of the relation between exposure and incidence (of adverse effects) is always limited. Practical restraints on the number of animals that can be tested means that the data are always subject to significant experimental error; it also means that only relatively high incidences; almost always greater than 10 percent, can be measured in the experiments. There is also no agreement about which mathematical models best extrapolate from the exposure levels measured in studies to those encountered in the environment. Linear models, which assume that incidence is proportional to exposure at low exposure levels, are used by Federal agencies."

Note that use of a linear model tends to be "conservative," i.e., it predicts a higher cumulative probability for harm at lower exposure levels. As a practical matter, there is often no alternative to the linear model. Figure VIII-2 shows a comparison of four models.

Apparently, there is no valid means to directly relate the probability for harm to a measured exposure level at low exposure levels. This situation poses another challenge:

- Estimation of the potential population who might be exposed to effects from the site and determination of the proportion of this population who might suffer harm as a result of the existence of the site.



EXPECTED INCIDENCE OF ADVERSELY EFFECTED FRACTION OF SUBJECTS EXPOSED TO VARYING DOSES WHEN A DOSE OF 1.0 ADVERSELY AFFECTS 50% OF SUBJECTS. FOUR MODELS USED FOR STATISTICAL EXTRAPOLATION.

SOURCE: OTA

Figure VIII.2. Comparison of four models used for extrapolation to estimate dose-effect relationships at low doses.

The proportion of the population in the exposure area who would be unaffected if the site did not exist can be found via application of the theory of competing risks. For example, a person in the exposure area may be ill for reasons entirely separate from the existence of the site. The elements of the problem may be stated as follows:

Given:

y = population in exposure area now who are not ill

u = population in exposure area showing adverse effects which might be attributed to chemical exposure via some path

z = population in exposure area who would be unaffected if dump did not exist

Required:

"z" in terms of "y" and "u"

Steps:

Let dz be the decrement of "z" in a small time.

Let dy be the decrement of "y" in the same small time.

If "z" individuals were subject to adverse effects due to chemicals, then

$$dz = \frac{z}{y}\, dy \qquad \text{(VIII-1)}$$

But: We must subtract from this value of dz the decrement arising from suffering of adverse effects caused from exposure to chemicals via some path. We must make such a subtraction since the "z" individuals are--by hypothesis of this problem--not liable. This decrement is

$$(z/y)\, du. \qquad \text{(VIII-2)}$$

Therefore:

$$dz = \frac{z}{y}\, dy + \frac{z}{y}\, du \qquad \text{(VIII-3)}$$

[We utilize +(z/y) du and not -(z/y) du since "z" and "y" decrease while "u" increases.]

Rearranging:

$$\frac{dz}{z} = \frac{dy}{y} + \frac{du}{y}, \text{ so} \qquad \text{(VIII-4)}$$

$$\log z = \log y + \int \frac{du}{y}, \text{ and} \qquad \text{(VIII-5)}$$

$$z = ye \int \frac{du}{y} \qquad \text{(VIII-6)}$$

At some time "x" incremented via dt, Equation (6) can be rewritten as

$$z = y \exp [\int_{o}^{x} \frac{1}{y} \frac{du}{dt} dt] \qquad \text{(VIII-7)}$$

The right-hand side of eq. (VIII-7) can--in principle--be estimated. But, in practice, obtaining the necessary data in unambiguous form and over a period of time represents a formidable, if not impossible, problem in epidemiology. Hence, there is likely to be great uncertainty in identifying members of the exposed population who suffer harm as a result of the hazardous waste site.

In fact, determining the exposed population, i.e., the group subjected to higher than baseline concentrations of the substances at the site, is no simple challenge. In principle, the various paths by which substances might reach the group can be identified. Monitoring, which relies on qualitative and quantitative determinations, at various points away from the site can be implemented. Thus, what--if anything--is escaping and how much will be known as a function of distance from the site. When the slope of the concentration against distance curve changes upward, the boundary for a particular path can be located. Wind, other climatic factors and water flow patterns may well alter the results over a period of time. Airborne or rain-based factors must be considered. Concentrations of substances produced by other means than the waste disposal site may intervene, e.g., from the plants generating the waste or other sources. Thus, attempting unambiguous identification of who is exposed to higher concentrations of potentially harmful substances from a waste disposal site is likely to be exceedingly difficult, time-consuming, expensive and inaccurate.

Parenthetically, the uncertainties in identifying unambiguously who is exposed as a result of only the waste disposal site and in identifying what portion of that population has suffered harm from the site are likely to make it exceedingly difficult to obtain appropriate insurance coverage since liabilities are undefined for generators, and victims cannot be associated with the site in any certain fashion.

At this point, the chief difficulty for the regulatory process should be clear: How to implement mandates to control possible risks associated with waste disposal in a fair, objective and accountable manner by using rational approaches such as scientific and technical data and cost-benefit analyses. These approaches tend to emphasize economic cost factors, but the concerned portion of the public generally considers that the health and environmental amenities at stake are unmeasurable in economic terms; in fact, most of the public probably wishes "zero exposure" from waste disposal.

If the regulatory process utilizes quantitative targets for defining a waste as "hazardous" and if exceedingly low concentrations of substances in the waste must be achieved, costs of control rise rapidly. Obviously, the lower the concentration, the higher the cost of control. Hence, some balance between these costs and exposure is needed. Once a risk is accepted as real, i.e., worthy of regulatory attention, the stringency of the regulation needs to consider economic and technical factors to be workable.

One proposed method for taking these factors into account is to apply some means to classify wastes destined for disposal into categories depending upon the substances, their concentrations and their propensity to move and/or to persist in the environment by any path. Thus, high concentrations of a known carcinogen which move rapidly and are persistent might require a more stringent level of control than lower concentrations of the same substances; a different substance which moved more slowly or was not a known carcinogen might require less control and so on.

In principle, this classification scheme is appealing since only the most objectionable wastes would require the most expensive monitoring and treatment. In practice immediate difficulties present themselves in how to set the classifications and to administer control over them in a fashion acceptable to the public.

Some of the technical difficulties will be apparent from an examination of table VIII.1 containing data which two objective and competent groups of scientists obtained in an attempt to assess cancer risk from drinking water containing one part-per-billion (one microgram per liter) of known carcinogens. The table purports to indicate the number of persons per million exposed who are likely to fall victim to cancer from drinking this water. Note that in several cases, a tenfold to hundredfold difference exists between the two estimates. While the possibility exists for arranging these carcinogens by probability for causing harm, doing so is not likely to be especially satisfying: The indication that 1,2-Dichloroethane may be twenty to one hundred times as to cause harm as Chlordane probably will not likely induce anyone to ignore Chlordane--at any concentration--in his drinking water. Furthermore, since proportionality between measured concentration and probability of harm is essentially unknown, and since the public is likely to insist on control at some point near the minimum detectable limit, additional study is needed.

Consider the situation prior to regulation of certain wastes. In many instances, these wastes went to pits, ponds, lagoons or landfills. Certainly, nature regulated the escape of certain substances into ecosystems. In addition, nature arranges matters such that if, in a population, "N", exposed

Table VIII.1. Concentration of Drinking Water Contaminants and Calculated Excess Cancer Risk

	NAS[a] 10^{-6} ug/l[c]	CAG[b] 10^{-6} ug/l[c]
Acrylonitrile	0.77	0.034
Arsenic	ND[d]	0.004
Benzene	ND	3.0
Benzo(a)pyrene	ND	ND
Beryllium	ND	0.02
Bis(2-chloroethyl)ether	0.83	ND
Carbon tetrachloride	9.09	0.086
Chlordane	0.056	0.012
Chloroform	0.59	0.48
DDT	0.083	ND
1,2-Dichloroethane	1.4	1.46
1,1-Dichloroethylene	ND	0.28
Dieldrin	0.004	ND
Ethylenedibromide	0.11	0.0022
ETU	0.46	ND
Heptachlor	0.024	2.4
Hexachlorobutadiene	ND	1.4
Hexachlorobenzene	0.034	ND
N-nitrosodimethylamine	ND	0.0052
Kepone	0.023	ND
Lindane	0.108	ND
PCB	0.32	ND
PCNB	7.14	ND
TCDD	ND	5.0×10^{-6}
Tetrachloroethylene	0.71	0.82
Trichloroethylene	9.09	5.8
Vinyl chloride	2.13	106.0

[a] Standardized to 10^{-8} risks from National Academy of Sciences Drinking Water and Health (266) for consumption of 1 l/water/day.

[b] Recalculated to exclude aquatic food intake from Cancer Assessment Group, Ambient Water Quality Criteria (104). Standardized to 1 l/water/day intake.

[c] Average adult water consumption is 2 l/day.

[d] Not discussed.

SOURCE: Office of Technology Assessment.

to emanations from the waste site, "P", individuals are harmed, a statistical estimation of the probability that "Q" individuals will actually be harmed is expressed by a Poisson distribution. The product NP is called λ, and tables of Q for a given λ can be found in most statistical texts.

If N is one million, and P is 10^{-6}, $\lambda = 1.0$ and we may be 37 percent certain that no one will be harmed and 100 percent certain that no more than five persons will be harmed. For ingestion of water from a hypothetical well containing the highest detected concentrations of commonly found contaminants, P has been estimated at 7.5×10^{-4} or if N is 1300, then $\lambda = 1.0$.

From the foregoing, the key to dealing with waste disposal of potentially harmful substances is to try to assume that these do not escape and to monitor carefully all sites--abandoned, existing or proposed. Where concentrations of potentially harmful substances have dropped to baseline levels, excess exposure does not exist. Hence, appropriate "on-line" monitoring is needed.

But, the key question remains:

- What technically valid and economically equitable means can be found to declare that a waste shall be deemed potentially harmful if some population is exposed to concentrations above baseline?

NBS/ORM addressed this question through several technical activities undertaken on behalf of other Federal agencies, e.g., DoE and EPA. Hazardous waste recovery and recycling activities as well as research involving test method development were undertaken with funds appropriated on behalf of RCRA, Subtitle E, mandates.

To implement the various sections of Subtitle C of RCRA, EPA has issued the following sets of regulations in Title 40 of the Code of Federal Regulations: (As of October 19, 1982)

Part 260:	Hazardous Waste Management System: General
Part 261:	Hazardous Waste Management System: Identification and Listing of Hazardous Wastes
Part 262:	Standards for Generators of Hazardous Wastes
Part 263:	Standards for Transporters of Hazardous Wastes
Part 264:	Standards for Owners and Operators and Hazardous Waste Treatment, Storage, and Disposal Facilities
Part 265:	Interim Status Standards for Owners and Operators of Hazardous Waste Land Disposal Facilities
Part 122: - 124:	Consolidated Permit Regulations (including permit regulations for hazardous waste facilities and State program authorization)

These regulations have been promulgated in several stages and are contained chiefly in the following Federal Register publications although there has been a continuing process of amendment.

1) 45 FR 33066, May 19, 1980: Parts 260-263 and 265, general provisions of Part 264, and Parts 122-124.

2) 45 FR 47832, July 16, 1980: Listing of additional hazardous wastes in Part 261.

3) 46 FR 2804, January 12, 1981: Parts 264 and 122, standards for storage and treatment facilities; and Parts 264, 265, and 122, standards for closure, post-closure care, and financial responsibility.

4) 46 FR 7666, January 23, 1981: Parts 264 and 122, standards for incinerators.

5) 46 FR 12414, February 13, 1981: Part 267, interim permitting standards for four classes of new land disposal facilities.

VIII.5. Analytical Test Methods and Standards

Certain wastes are listed under RCRA regulations as hazardous; well over 100 substances are on these lists. Usually some limiting value of concentration above which the material is deemed hazardous provided and associated with each substance in various media, e.g., water, soil, air. Therefore, some valid sampling procedure for each waste stream is needed as well as appropriate qualitative and quantitative analytical procedures. Unhappily, the heterogeneity of potentially hazardous wastes and the need to analyze for mixtures of compounds at very low levels can introduce a large amount of uncertainty into the sampling and analytical results.

Much of the NBS/ORM sponsored research dealt with sampling analysis and development of standards for potentially toxic wastes. (NBS/ORM Publication List #'s 80, 92, 94, 113, 114, 118, 119 and Appendices V and VI give details of published results to date).

A major effort of the scientific and regulatory community has been in developing a simple, relatively inexpensive, extraction procedure (EP) protocol which will test whether potentially toxic wastes can be leached from parent entities, e.g., solid waste mixtures, liquids in soil. The regulatory community must decide on an appropriate upper limit of concentration for each toxic constituent in the leachate obtained via any EP; wastes failing the test are designated hazardous. Note that no "degree-of-hazard" is implied-either the waste is or is not prescribed as a result of the EP test.

Thus, development of an equitable, universal test whose precision and accuracy are well documented is necessary. NBS/ORM applied considerable effort to these tasks. A rotary shaker for the extraction process was designed, developed and tested at NBS

(Publ. #118); this shaker design was incorporated into the existing Federal regulations.

The question of reproducibility of various EP test results is still unanswered. NBS has been actively concerned with statistical analysis of analytical results from leached samples involving both organic and inorganic species at trace levels. Appendix VI deals with this question in some detail.

In view of the uncertainties, NBS/ORM decided to develop a synthetic leachate trial standard which would contain known amounts of several compounds of interest and could be used for interlaboratory comparison purposes. Appendix V shows the results of one set of experiments. Clearly, the yield depends on both concentration and time of storage for all compounds studied in the experiment. As shown in Appendix V, yields vary with type of compound as well. For example, in the case of quinoline, the percentage yield, Y, is:

$$Y = 68.5 + 1.2C - 0.10_{4}t \qquad \text{(VIII-8)}$$

where C is the concentration in PPB and t is the time in hours from specimen preparation to analysis. (Result valid in range $5 \leq C \leq 25$ PPB and $0 \leq t \leq 50$ hours). But for benzo (1) anthracene, the percentage yield is

$$Y = 116.3 - 0.15C_{x} - 0.67_{9}t \qquad \text{(VIII-9)}$$

Because of the complexities, I have decided to include as Appendix VI fairly complete descriptions of the experimental procedures, results and statistical evaluation of several of the NBS experiments. Careful review and reflection of these results yields some understanding of current difficulties in establishing a suitable EP test procedure. A universally satisfactory and scientifically acceptable protocol still remains to be developed. The NBS/ORM investigations have provided an important foundation for the development of such a protocol, but considerably more research is required. In this regard, NBS and DOE have collaborated, under DOE sponsorship, to produce a major compendium of the development of analytical methods for the determination of organic compounds in fossil fuel aqueous leachates (Publ. List #125.)

At present, the NBS developed synthetic leachates can be used to test analytical procedures. Certain NBS SRM's can be used to test the EP itself. Indeed, NBS used just such a procedure. (Publ. list #113) Definitive sampling and test protocols do not exist, however. There is considerable controversy concerning what leaching medium to utilize, e.g. water, acetic acid buffered to a pH of 5, citric acid, etc. and how long the sample should be exposed to the leaching agent. (See Publ. List #'s 113, 114, 119 and Appendix VI).

Some idea of the uncertainties which may arise can be obtained from a simple example involving the hypothetical analysis of quinoline in water. Assume four replicate analyses yielding concentrations of 12 PPB, 19 PPB, 15 PPB and 14 PPB respectively. The mean is 15 PPB while the measured standard deviation, s_{N-1} is 2.94. If the analytical procedure was performed 24 hours after sampling, the yield eq. (VIII-8) can be used to correct the measured values. The new mean value is 17.8 PPB. The total effect of the variable yield is shown in figure VIII.3 in which the cumulative probability for the true mean as a function of concentration is shown for the original data set and the set corrected for yield. Effects which may arise when several organic constituents are present in a leachate mix are likely to be extremely complex. One prudent means of dealing with such complexities might be imposition of some "safety factor" meant to encompass losses due to yield effects or synergistic effects. (Note that the increase from a mean of 15 PPB to 17.8 PPB in the hypothetical example represents about a 19 percent relative increase in risk if risk is linear with concentration in the range 10 to 20 PPB for quinoline.) However, selecting an appropriate means to equitably set such a safety factor would require considerable further research.

VIII.6. Current Approaches--Degree of Hazard

Despite the difficulties and uncertainties associated with the accurate measurement of the concentration of a potentially hazardous constituent, some means of classifying various waste streams with a view towards selecting appropriate environmental treatment, storage, recycling or disposal options at an affordable cost is needed. There is considerable effort being expended to evaluate possible options and to develop reasonable methods or models for the selection of the "best" course of action with respect to a given waste stream. Specifically, the Office of Technology Assessment of the U.S. Congress is evaluating a degree-of-hazard approach while the U.S. Environmental Protection Agency has commissioned the development of a Waste-Environment-Technology (W-E-T) Matrix. According to the developers of this model:

> "The RCRA Risk/Cost Policy Model establishes a system that allows users to investigate how trade-offs of costs and risks can be made among wastes, environments, and technologies (W-E-T)) in order to arrive at feasible regulatory alternatives.
>
> "There are many components in the system. Eighty-three hazardous waste streams are ranked on the basis of the inherent hazard of the constituents they typically contain. The system assesses these waste streams in terms of the likelihood and severity of human exposure to their hazardous constituents and models their behavior in three media--air, surface water, and ground water. The system also incorporates the mechanisms by which the constituents are affected by the environment, such as hydrolysis, biodegradation, and adsorption.
>
> "A second integral part of the system is the definition of environments in which the hazardous components are released.

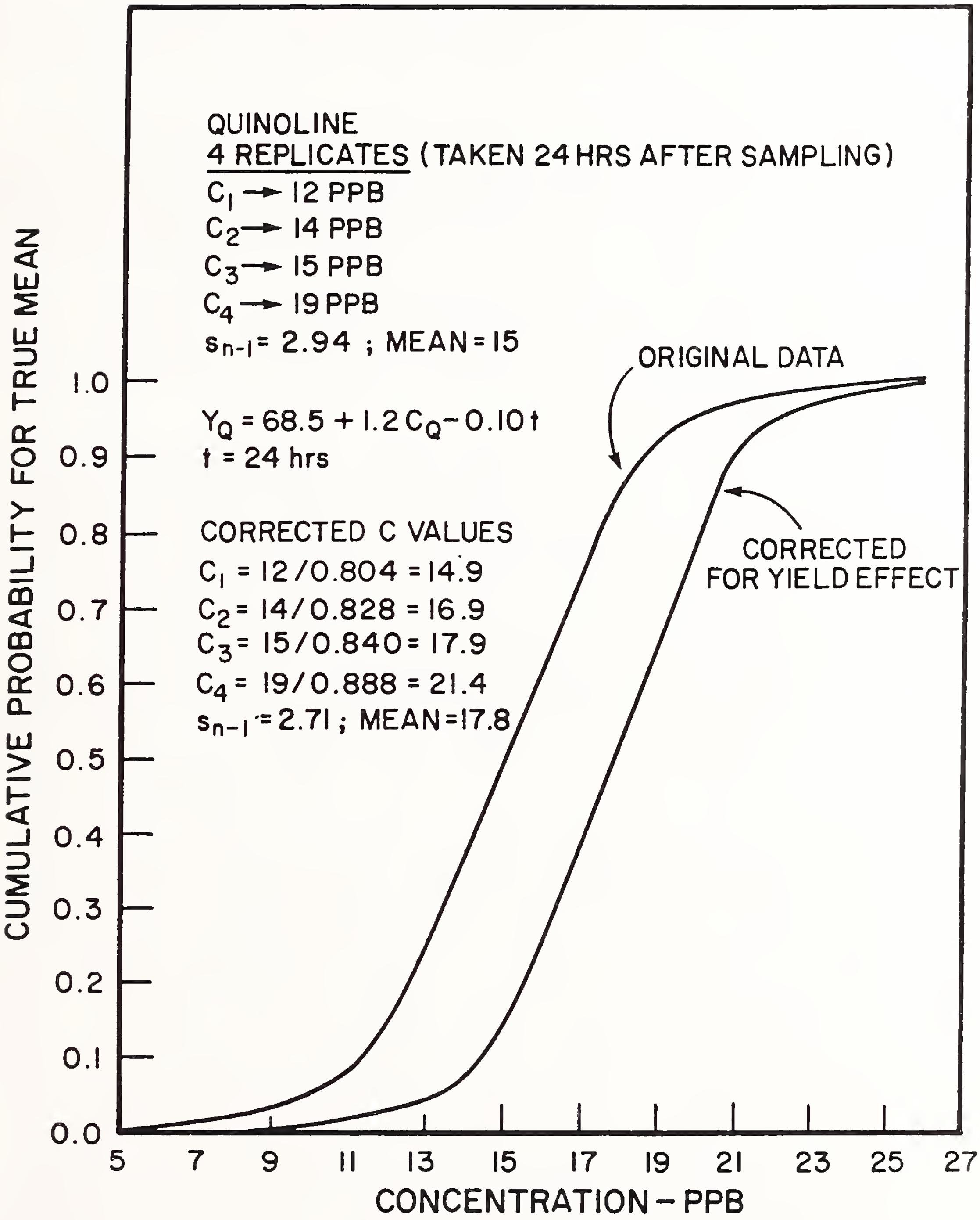


Figure VIII.3. Effect of analytical uncertainties on determination of concentration traces of organics in water. Hypothetical data for quinoline determination are shown for illustrative purposes.

> Thirteen environments including a special category for deep ocean waters are defined on the basis of population density, hydrology, and hydrogeology. The system adjusts the exposure scores of the waste streams' hazardous constituents to account for their varying effects in the three media in each of the environments.
>
> "The third component of the system consists of the technologies commonly used to transport, treat, and dispose of the hazardous waste streams. This includes three types of transportation, 21 treatment technologies, and nine disposal technologies. The system determines costs and release rates for each of these technologies based on the model's existing data base. It also incorporates estimates of capacities of the technologies, the amount of waste to be disposed of, and the proximity of the wastes to the available hazardous waste management facilities.
>
> "EPA's purpose in developing the RCRA Risk/Cost Policy Model is to assist policymakers in identifying cost-effective options that minimize risks to health and the environment. The framework of the system is intended as a screen--to identify situations that are of special concern because of the risks they pose and to determine where additional controls may not be warranted in light of the high costs involved. The framework uses a data base that is too imprecise and general to be the sole basis for regulations. The results of the model will be used in more detailed Regulatory Impact Analysis to determine whether some type of regulatory action is warranted."

NBS/ORM, in partial fulfillment of the mandates of sections 5002 and 5003 of RCRA, utilized some of the results of hazard scoring used in the W-E-T model in order to suggest certain statistical inferences for assessing degree of hazard posed by certain substances. This work is included as Appendix VII. As reported by the model builders, scores in the range 0 through 12 provide an index of increasing hazard. The NBS/ORM evaluation suggests that for scores up to 5 or 6, there is a "low" hazard band, for scores of 6, 7 there is an intermediate band and for 8 and above, there is a high band. Hence, one possible suggestion is that low band materials may be candidates for lowest cost options, e.g., landfill. High band materials may be candidates for destruction while specific local details may indicate appropriate action with regard to intermediate band materials. However, each decision needs to be based upon a wide variety of data such as proximity of ground water, cost, citizen attitudes, state and local requirements and many others. Still, the basic options for dealing with potentially hazardous waste are recycle or reuse if economically and technically feasible, dispose either by burial or destruction if not. Note that "destruction" may include transformation to innocous products via thermal treatment and/or chemical treatment, e.g., wet air oxidation or incineration. NBS/ORM examined the recycle, bury or burn options in some detail.

VIII.7. Hazardous Materials Incineration

VIII.7.a. General

Work was divided into three distinct areas: a) Acquainting the Hazardous Materials Incineration community with the existing technology base in combustion kinetics. b) Development of a better understanding of the technical problems of the industry and thus opening up new areas where chemical kinetics can make contributions. c) Development of laboratory facilities with the aim of answering specific fundamental questions.

In the first area 12 lectures were presented on the chemical kinetics aspects of hazardous waste incineration. Aside from purely technical meetings presentations have been given before regulatory bodies such as the California Air Resources Board, EPA headquarters and laboratories and field offices, and trade and professional organizations such as the Chemical Manufacturer's Association and the ASME Research Committees on Municipal and Industrial Wastes. NBS personnel took a leading role organizing meetings for JANNAF on Hazardous Waste and the role of remote sensing; a second meeting dealing with DOD hazardous waste disposal problems was held in October, 1982 in Redstone, Alabama.

The fundamental problems in this area arise from the fact that although incineration is an old technology, it has always been used as a volume reducer. The concepts and techniques for assuring total destruction of organic compounds are often foreign to the practitioner of this technology. The NBS role may be viewed in terms of technology transfer thus facilitating the use of incineration as a hazardous waste disposal technique.

The foregoing was concerned with the destruction of listed hazardous wastes and the factors that makes one substance more difficult to destroy then another. NBS has studied the formation of toxic chemicals and the role of tracers during incineration. With respect to the former, NBS has concentrated on dioxin formation. For this purpose chemical kinetic models have been set up using a number of possible mechanisms. Although the experimental data base is sketchy, it does provide a basis for making worst case estimates of the elementary rate processes. The results have been surprisingly informative in terms of the relation between the amount of dioxins that can be produced, the necessary type of precursors and the possible mechanisms by which it may be produced. These considerations also lead to the possibility that detection of dioxins in incinerator effluents may simply be an indication that they were present in the input stream. A paper has been prepared and is included as Appendix III.

Present EPA regulations for hazardous waste incinerators require a capability to destroy 99.99 percent of selected Principal Organic Hazardous Components in a waste mixture. The analytical requirements for demonstrating such a capability are quite severe and rendered more difficult by the fact that each hazardous waste mixture may have different POHCs. EPA contractors have in fact reported difficulties in carrying out required procedures. The total cost of such tests has been estimated to be of the order of $50,000 by EPA and $100,000 to $200,000 by industry. Furthermore, one notes that there is no way of assuring that regulations are still being met for a previously qualified incinerator. Thus, it is natural to consider the introduction of tracers or a number of tracers is that span the range of chemical stabilities. This method can simplify the analytical problems in permitting the development of specific analytical techniques for a limited number of related compounds and indeed it may be possible to exploit some particular property of the tracer. On this basis per-fluorinated hydrocarbons appear to be particularly suitable. In an incinerator environment, radical attack will be slower than that of ordinary hydrocarbons, and stability in the unimolecular sense decreases with increasing molecular size (for per-fluorinated alkanes). One can thus scan the full range of chemical stabilities. Equally important, per-fluorinated hydrocarbons produce unique gas chromatographs and have unique infa-red characteristics. Gross simplifications of analytical procedures are possible; and, the possibility of real-time monitoring becomes feasible. There are, however, certain problems. These include the introduction of such tracers and-perhaps most important-complications arising from unburnt hazardous wastes that may be present in particulates. We are currently considering the aspects of the problem; preliminary results are shown in Appendix VIII.

An important aspect of the program is the direct experimental verification of the predictions that have been made. We are in the process of putting together a flow reactor which simulates the incinerator environment. Particular attention has been paid to minimize the effect of the reaction wall. The data acquisition system and all the hardware have now been delivered. The first system to be studied will be various chlorinated aromatic compounds. Succeeding studies will be directed towards checking our proposed scale of incinerability and the effectiveness of the per-fluorinated compounds as tracers. It may also be possible to make some estimates of rates and mechanisms of formation of various Products of Incomplete Combustion (PICS).

Considerable work remains to be done. For example, EPA contractors have apparently concluded that proposed incinerability ranking procedures are inappropriate and that incinerability differences are both small and dependent on the specific system chosen (EPA Contract 68-03-3113, November 16, 1982). Thus, despite cessation of the formal NBS/ORM program, research in this area will probably continue with other agency funding.

VIII.7.b. Incineration at Sea

A special case for incineration of hazardous wastes involves thermal destruction at sea. If this step is taken, then difficulties in siting may be removed since the destruction site is about 100 miles offshore. Furthermore, the most noxious wastes can be dealt with. At present, several firms are interested in pursuing the option of incinerating liquid wastes at sea.

The U.S. Maritime Administration (MARAD), which was a part of the Department of Commerce until July 1, 1981 when it was transferred to the Department of Transportation, took a strong interest in incineration at sea. At the request of MARAD, and in partial fulfillment of responsibilities under section 5003 of RCRA, NBS/ORM participated as a member of the Interagency Review Board of the Chemical Waste Incinerator Ship Program which coordinated all Federal establishment activities related to developing an incineration at sea capability in the United States.

The Board concluded that:

1) A high priority effort is required to solve the nation's hazardous waste disposal problem. A privately-owned incinerator ship service could be available by 1985 or sooner and would make a significant contribution to alleviating the current extreme shortage of viable waste destruction facilities.

2) Adequate laws and conventions exist to regulate incinerator ship design, construction, and operation.

3) Federal maritime assistance is currently available to encourage private U.S.-flag incinerator ship construction. Federal ship loan guarantees are obtainable based on standards of technical and economic soundness. In addition, ships from the National Defense Reserve Fleet may be sold for conversion to incinerator ships.

4) A U.S.-flag chemical waste incinerator ship capability is not likely to develop without substantial federal assistance, e.g., coordinated certification and permitting, federal waste destruction contracts, and additional maritime aids.

5) Several new construction incinerator ship conceptual designs were developed. A design with 7,560 metric tons of hazardous waste capacity was selected as a potentially viable dual-mission demonstration vessel for routine destruction of liquid wastes and for experimental incineration of solid wastes.

6) Conversion designs of existing National Defense Reserve Fleet ships were evaluated and determined to be less costly but inefficient investments compared to a new incinerator ship for the dual mission of destroying large volumes of pumpable wastes and conducting experimental solid waste incineration.

7) Waterfront integrated hazardous waste management facilities are necessary to support U.S. incinerator ships. Such a

facility would include waterfront storage tanks; waste receiving, processing, and handling equipment; a laboratory for waste analysis; and a transfer terminal for loading wastes aboard ship. (see Publications List #90, for full details of the Board's program).

A major NBS/ORM activity on behalf of the Board was to determine what technical issues underlay the development of efficient, safe, and economical systems for the disposal of hazardous chemical wastes at sea. This challenge poses conventional and unique technical problems in materials handling as well as in incineration process and its aftermath. Problems in materials handling encompass:

- materials handling and storage hazards;
- determination of the mechanisms and rates of degradation of selected compounds in storage, handling, and under high temperature conditions; and
- durability and reliability of construction materials (metals, ceramics, and polymers such as liner materials).

The incineration process and its attendant health and environment concerns pose questions concerning:

- thermodynamic properties of combustion products;
- development of standard reference materials and methods for defining incinerator operating conditions;
- determination of nature and reactivity of combustion gases as well as measurement of gases, vapors, liquids, particles of toxic metals, metallo-organics, carcinogenic and toxic compounds; and
- characterization and monitoring of specific effluents and effluent clean-up and systems control and mitigation of specific emissions.

Each of these problems requires development of essential materials data, test techniques and methodology for materials properties, design and performance modeling including prediction of materials properties and chemistry.

The NBS Center for Chemical Physics (CCP) has identified technical areas of concern which are:

- Determination of the mechanisms and rates of degradation of selected compounds under a wide variety of high temperature conditions: Although specific hazardous compounds have not been studied, the methodology is general and can lead to determinations of the conditions necessary for 99.99 percent destruction and the variety of reaction products to be expected. The key to such studies is the determination of reaction products and intermediates. For this purpose CCP has state-of-the-art capabilities in all current methodologies including chromatography, and mass spectroscopy as well as infa-red and optical spectroscopy under. Note that this range of capabilities can also be applied to monitoring and controlling incineration and in fact to the entire materials handling process. Furthermore, the NBS capability extends to the detection and identification of new species. This is particularly important for the at sea incineration application since most of the substances have not been previously studied.

Past experience has demonstrated that the behavior of related compounds follows well-ordered patterns. Thus from a few well characterized systems, extrapolations of considerable validity can be made. For example, if one considered pesticides as typical hazardous materials, one would expect a variety of the nitrogen and sulfur-based compounds to be more readily destroyed than analogous hydrocarbons--while chlorinated aromatic compounds are probably more stable. The Chemical Kinetic Data Center has produced evaluated data in this area and is responsible for the development of the kinetic data base for stratospheric chemistry (ozone depletion problem). This center is presently developing a similar information base for combustion kinetics.

- Defining Incinerator Operating Conditions, Methods, and Standard Reference Materials: For the case where one is asked to deal with a material with no previous knowledge regarding degradability, it is reasonable to conduct preliminary studies on bench scale units. This approach however leads to problems in scale-up. A possible solution is to define a standard reactor and standard operating procedures. Coupling a standard reactor and operating procedures with a well characterized series of calibration compounds, spanning the operating range of the incinerator, allows one to define the behavior of the new samples in terms of the behavior of the calibrants. From such data it should be possible to deduce the proper operating points for incineration.

- Thermodynamic Properties of Combustion Productions: Probably the most uncertain problem in hazardous waste disposal is the nature of the combustion products. Determination of mechanisms and rates are aided immensely by thermodynamic knowledge. Evaluated data as well as estimates are required. The NBS experimental facility, still under development, is similar to small incinerators and is particularly well instrumented. One suspects that at the very least the technology if not the instrument itself can be adapted for the new application.

- Materials Handling and Storage Hazards: In the handling and storage of chemicals the possibility of exothermic self-reaction or auto-oxidation leading to spontaneous combustion must be considered. State-of-the-art expertise and instrumentation along with differential scanning calorimeters and an absolute reaction calorimeter are available. Currently CCP is using a high pressure Differential Scanning Calorimeter to study the auto-oxidation properties of recycled oils. There are marked similarities between and with regard to approach and problems in handling industrial wastes. The integrity of the containers in the restricted confines of a ship must be of considerable concern. A large array of real time monitoring instruments will be a necessity. State-of-the-art laser based devices with high sensitivity and high resolution may be applied to this problem.

- Nature and Reactivity of Combustion Gases: This problem is concerned with the major components in the combustion of complex substances. The interest lies with their interactions with each other and with incinerator surfaces. A fundamental attack on corrosion problems that may arise during incineration operations will be required.

- Effluent Clean-Up: If the proposed incinerator must meet all land-based environmental regulations, a variety of state-of-the-art clean-up techniques must be employed. Therefore, the possibility of ozonizing aqueous effluents may well be worth investigating. Currently CCP is carrying out programs dealing with the fundamentals of SO_2 scrubbing from power plant effluents, and the fate of toxic chemicals, in aqueous media.

The Center for Materials Science (CMS) has identified the following areas requiring investigation by class of material (metals, ceramics, polymers, composites).

- Assessment of stress-corrosion fatigue cracking of containment and transfer materials.

- Non-destructive inspection procedures for containment structural alloys and their welds.

- Establishment of fracture control planning for containment and transfer systems.

- Corrosion resistance and other compatibility properties of containment and transfer materials (metals, ceramics and polymers).

- Identification of significant corrosive combustion products and their attack on system components.

- Development of methodology for monitoring specific compounds (primarily metals in effluents).

- Modelling the effect of inorganic elements on combustion efficiencies.

The Center for Analytical Chemistry has outlined a measurement quality assurance program utilizing numerous chemical analyses to ensure the proper functioning of sea-based incineration system.

A measurement quality assurance program requires supporting research program in the Center that would include, but not necessarily be limited to, the following:

- multielement analysis for screening of wastes and residuals such as ash;
- organic analysis focusing on screening techniques for criteria pollutants;
- gas analysis for toxic effluents; and
- particle analysis including identification of organics and toxic heavy metals which adhere to particles.

With respect to the development of criteria for measurement of the ability of the vessel to adequately destroy specific and blended wastes, the essential requirement for hazardous waste incineration is destruction at the 99.99 percent level. In the case of mixtures, the suggested procedure involves selection of the Principal Organic Hazardous Component and the demonstration of the capability for destruction. There is at present the controversy regarding the methodology for the selection of POHCs. In view of this uncertainty it is likely that a number of compounds will have to be tested.

Individual compounds require analytical methods of high specificity. Gas chromatography is the method of choice, but (considering the expense) a gc-ms set-up may not be necessary if the proper choice of waste streams for the research burns is made. The destruction limits imply that less than 0.01 percent of the surviving compound can be detected. In view of the dilution upon combustion, nitrogen of the air and the fact that the POHCs may be present in small amounts, the need for detection limits at the 1-100 ppb level is essential. This is just about the limit of sensitivity of current g.c. instrumentation equipped with flame ionization or electron capture detectors. Thus it would probably be necessary to pre-concentrate samples. The methodology for this and the collection of gas samples exists but can be subject to experimental artifacts and considerable thought must be given to how experiments are to be carried out. These tests should probably be carried out on shipboard since during the research burns one would presumably want to correlate destruction efficiency with the various processes and control variables. A certain number of samples should be preserved for subsequent analysis upon return to port. The integrity of such samples is a problem to be considered. Important decisions must be made regarding nature, siting and contents of a shipboard laboratory. Measurement of total hydrocarbon emissions (T-H-E) should be made. T-H-E is a variable which like the combustion efficiency may in the future provide a surrogate means of determining destruction efficiency. In both cases however, the methods for making the measurement, the placing of probes etc. should be carefully considered. In the future, the possibility of non-intrusive optical probes in the incinerator represent an important analytical direction. Finally provision should also be made for additional thermocouples. Additional ports must be available for making such measurements when the need arises.

In addition to incinerator monitoring on ship, there are a host of equally important ancillary problems; for example, analysis of input streams, heating values, compatibility of different wastes, blending, stability etc.

In summary, NBS findings with respect to measurement protocols for monitoring of the incineration process aboard ship were as follows:

1) There must be some means on board the ship to accurately monitor emissions from the stack and the combustion process itself, in order to determine whether or not the requirement for 99.99% destruction is satisfied. Since we deem it, at best, impractical and, at worst, impossible to measure "destruction" directly, it is necessary to develop a protocol for determining a surrogate relationship between the measurement of the combustion process (emissions) and the destruction ratio.

2) Such a protocol must be developed for each waste stream to be incinerated. The protocol should be employed in a test burn after on-shore blending or ship-board blending has occurred. An apparatus similar to the NBS 2.5 kg calorimeter would be appropriate to conduct the test burn. Determination of the characteristics of each waste stream prior to commercial at sea incineration is necessary since 1) operators must be cognizant of blended waste's reaction in combustion process; 2) operators must be able to verify achievement of destruction efficiency on basis of monitoring data; and 3) operators must be able to verify that the products of combustion will not imperil either the crew or the environment.

3) A means to measure the heat value of the various waste streams is also necessary; this method can be an apparatus equivalent to the NBS 2.5 kg calorimeter.

4) Further research is necessary to define the parameters of the combustion process in order to determine the appropriate monitoring system and surrogate measurements which will 1) assure that the tests will be definitive with regard to the required destruction (see Appendix VIII),

and 2) will be economically supportable (i.e., least costly).

Clearly, many of these same measurement protocols could be adapted for use with land based incineration systems with little or no change.

In any event, on April 16, 1982 the Federal Government, acting under authority of Title XI of the Merchant Marine Act of 1936, approved a guarantee of a loan to finance construction of two U.S. flag ships intended to incinerate hazardous chemical wastes at sea. Subject to MARAD final approval of the applicant firm's financing arrangements, the loan guarantee covers $55,875,000 or 75 percent of total anticipated construction costs. The ships are currently under construction and are expected to be launched in late 1983 or early 1984. Presumably, the measurement protocols suggested by NBS will be implemented on these and other similar incinerator vessels. Each of the two ships will accommodate 6200 tons of waste to be destroyed with the aid of two liquid injection incinerators having a combined processing rate of 20 tons per hour. These vessels will conduct operations at Federally designated sites about 100 to 150 miles off-shore. Under these conditions, the two ships can deal with a total of about 250,000 tons of waste annually.

VIII.8. Land Disposal

With respect to land disposal of potentially hazardous waste, NBS/ORM was concerned with the durability of polymeric liners which might be used in an attempt to isolate the waste from its immediate surroundings. Indeed, present regulations call for liners under a wide variety of conditions. Depending upon specific conditions, either a single or double liner is required.

A successful polymeric liner must retain its mechanical and barrier properties in the presence of permanent contact with water containing diluted hydrophilic or suspended hydrophobic substances or solid particles. The first two kinds of material may diffuse into the polymer and eventually transform into a soft rubbery material or even disintegrate it by chemical attack. Solid particles may abrade the polymer surface and thus gradually degrade the useful properties of the polymer.

Hence, a special study is needed to select the proper polymeric materials to be used as a liner for a given industrial or other effluent waste. Three types of action have to be considered: 1) diffusion with the ensuing lowering of the glass transition of the swollen polymer; 2) oxidative or any other type of chemical action which may lead to the disintegration or at least softening of the polymer; and 3) mechanical stress or abrasion. The effects are not independent. They may be strongly synergistic. As a polymer softens it becomes much less abrasion resistent. The softened or disintegrated material as a rule permits a much faster diffusion of penetrants than the unaffected material.

NBS/ORM determined the mass loss and sorption/desorption of Acetic Acid (HAc) in polyethylene of different densities at various temperatures. Mass loss studies for a mixture of HAc and H_2O (three concentrations) were also done at the highest temperature used. Loss rate, diffusivity, solubility and permeability of HAc were measured. (See Publications List #119 for full details). Appendix IX contains a brief overview of possible research approaches meant to aid in determining the compatibility of polymeric liner materials with hazardous wastes.

VIII.9. Technical Issues Relating to Disposal Site Evaluation and Rating

All of the work described in this category was undertaken in response to Section 5003, Part (2) of RCRA dealing with identification of economic and technical barriers to the use of recovered materials. Technical issues associated with estimating the potential risk caused by certain waste substances were evaluated. Then the technical and economic issues were melted together via joint efforts with the States and the Organization for Economic Cooperation and Development (OECD).

The W-E-T model approach or similar degree of hazard classification scheme is useful for rough-cut general policy, technical and economic guidance. But, of practical necessity, a "general" model must have very broad categories. A more precise approach is desirable to deal with specific conditions at an existing, proposed or even abandoned land disposal sites. Fortunately, such an approach has been developed by Dr. David H. Rosenblatt and co-workers at the U.S. Army Medical Bioengineering Research and Development Laboratory, Ft. Detrick, Maryland. This approach derives preliminary pollutant limit values (PPLV's) for effects on human health, but effects on other species or ecosystems can be obtained by using a similar methodology. After a brief discussion and explanation of the PPLV method, the W-E-T and PPLV approaches will be shown to be fully complementary.

The PPLV concept leads to an environmental fate model for chemicals in soil and water in which the allowable levels are determined by the acceptable daily intake of humans. The PPLV is based on existing data that relates primarily to human health effects, e.g., Handbook of Chemical Property Estimation Methods (W. J. Lyman, W. F. Reehl and D. H. Rosenblatt, McGraw-Hill, 1982). The PPLV concept treats each pathway by which humans may be exposed to potentially hazardous substances as a series of compartments. Equilibria are assumed to exist between successive compartments except between the next-to-last compartment and a human. Often the final step depends upon dietary intake. For each path by which the substance may reach the human, a single-path PPLV (SPPPLV) can be calculated. The final PPLV is derived by normalizing all SPPLVs.

The developers of the concept state as follows:

"Common sense should always be exercised in the derivation and use of PPLVs. These values should always be derived with careful consideration of the site-specific conditions. The PPLV model should be regarded as a frame-work that can be modified to account for site-specific elements. The temptation to develop and institutionalize PPLVs as standards should be avoided. Each value should be given a mandatory date for reconsideration, and the data base used in the formulation should be continually updated and examined.

"An experimental approach to determining environmental pollutant standards is certainly preferable to the extensive reliance on assumptions that characterizes the PPLV procedure; the principal merit of the PPLV is that it can be determined even in the absence of complete data. Where data gaps are sufficient to warrant experimental research, available resources can be properly allocated by specifying research only for key parameters identified by the PPLV-determination process.

"The PPLV is determined in six steps:

- Pollutants and pathways are identified.
- An acceptable daily dose of toxicant (D_T) and partition (intermedia transfer) coefficients are determined or estimated.
- Relevant data are gathered from the literature.
- SPPPLVs are calculated for all pathways (not site-specific).
- Critical pathways for each pollutant are selected (often site-specific).
- The PPLV is derived by normalization of SPPPLVs.

"Normalization adjusts the pollutant concentration where pathways originate in the same medium or have a common point of intersection. A simple calculation, similar to adding electrical resistances in parallel DC circuits, is used, such that SPPPLVs taken together provide the target organism, man, with an exact D_T. The following equation describes the calculation of a PPLV from SPPPLVs via three pathways from water:

$$\text{PPLV} = 1 \div [1/(\text{SPPPLV})_1 + 1/(\text{SPPPLV})_2 + 1/(\text{SPPPLV})_3]$$

"The approach used in calculating SPPPLV's assumes contaminants to be in stepwise equilibrium (steady state) from source to receptor."

For complete details of the PPLV concept, see J. C. Dacre, D. H. Rosenblatt and D. R. Cogley, Environmental Science and

Technology 14, 778-784 (1980) and D. H. Rosenblatt, J. C. Dacre and D. R. Cogley, "An Environmental Fate Model Leading to Preliminary Pollutant Limit Values for Human Health Effects", Chapter 15 of Environmental Risk Analysis for Chemicals (R. A. Conway, ed.) van Nostrand Reinhold (1982).

A number of PPLVs have been developed for various sites. For example, in one scenario-involving polybrominated biphenyl (PBB) which had been deposited in a landfill in Michigan--a PPLV for water consumption by animals and humans from the groundwater aquifer beneath the disposal site was calculated as 2.4 PPB. (D. H. Rosenblatt and R. J. Kainz, U.S. Army MBRDL Technical Report 8204, 35pp, 1982).

This value of 2.4 PPB is extremely difficult to measure accurately. Indeed, detection limits for many organic species in water are on the order of 5 PPB. The yield uncertainties, as shown in Appendix V, complicate the analysis challenge even further. NBS/ORM personnel considered this situation with a view towards suggesting a relationship between measurable quantities and PPLVs in terms of probability of risk to a given exposed population.

If the value of 2.4 PPB of PBB in water is, in fact, a concentration for which the possibility of harm is nearly zero, then an appropriate means to deduce the probability for no individual in a population exposed to (ingesting) water derived from the aquifer can be derived. The assumptions are as follows:

1) Risk is linear with concentration in the region of interest; this relationship is presumed to have some positive slope, designated as "m";

2) Exposure at PPLV level leads to a risk of adverse effect from the contaminant of one in ten million (10^{7}) in the exposed population;

3) The exposed population is "N";

4) A Poisson distribution will represent the risk of the adverse effect in the population; and

5) Some value of concentration, C_x, of contaminant(s) can be measured.

Under these conditions, the Poisson parameter, λ, can be expressed as:

$$\lambda = mN\ (PPLV). \qquad \text{(VIII-10)}$$

The probability, P_o, that no individual in the exposed population will be harmed is

$$P_o = e^{-\lambda} = \exp - [mN\ PPLV)]. \qquad \text{(VIII-11)}$$

For $P_o = 0.9999$, i.e., a 99.99 percent chance that no individual in the entire exposed population may be harmed, $\lambda = 10^{\ 4}$. Thus,

$$mN = \frac{10^{-4}}{PPLV} \quad \text{for } P_o = 0.9999. \qquad \text{(VIII-12)}$$

Whatever the exposed population:

$$\lambda = \frac{10^{-4} Cx}{PPLV} \qquad \text{(VIII-13)}$$

$$P_o = \exp - \left(\frac{10^{-4} Cx}{PPLV} \right) . \qquad \text{(VIII-14)}$$

Figure VIII.4 shows P_o as a function of the ratio of C_x to PPLV; extrapolation much beyond the limits shown in figure VIII.4, i.e., $C_x \div$ PPLV of 725 is probably not justified. Note, however, that even if this ratio is as high as 100, then there is still a 99 percent chance that no individual in the exposed population is likely to be harmed.

The value of the PPLV concept can be summarized as follows:

1) PPLV can be used as a datum, given specific conditions, such that any site whose contamination level is equal to or exceeded by PPLV can be declared "clean", i.e., non-hazardous to health. Thus, the "How clean is clean?" issue can be addressed with a valid target;

2) The PPLV concept is independent of exposed population; and

3) A simple direct relationship exists between measured concentration in some medium, e.g. ground water and the probability that no individual will be harmed if PPLV can be used to represent the concentration for which there is a 99.99 percent probability of no harm. Thus, analytical uncertainties can be taken into account via "worst case" computations of P_o. For example, in the quinoline case discussed previously, the measured mean of 15 PPB corresponds to a probable "true" mean of 18 PPB. Assuming the 15 PPB was even 150 times greater than PPLV, P_o is 0.985. If the true concentration were 18 PPB, then P_o is 0.982. Analytical uncertainties become increasingly important, in terms of probable risk to a population, when C_x exceeds PPLV by a factor of 200 or more. (See Appendix XIV for Details).

The relative error in P_o can be estimated by differentiation of eq. (VIII-14):

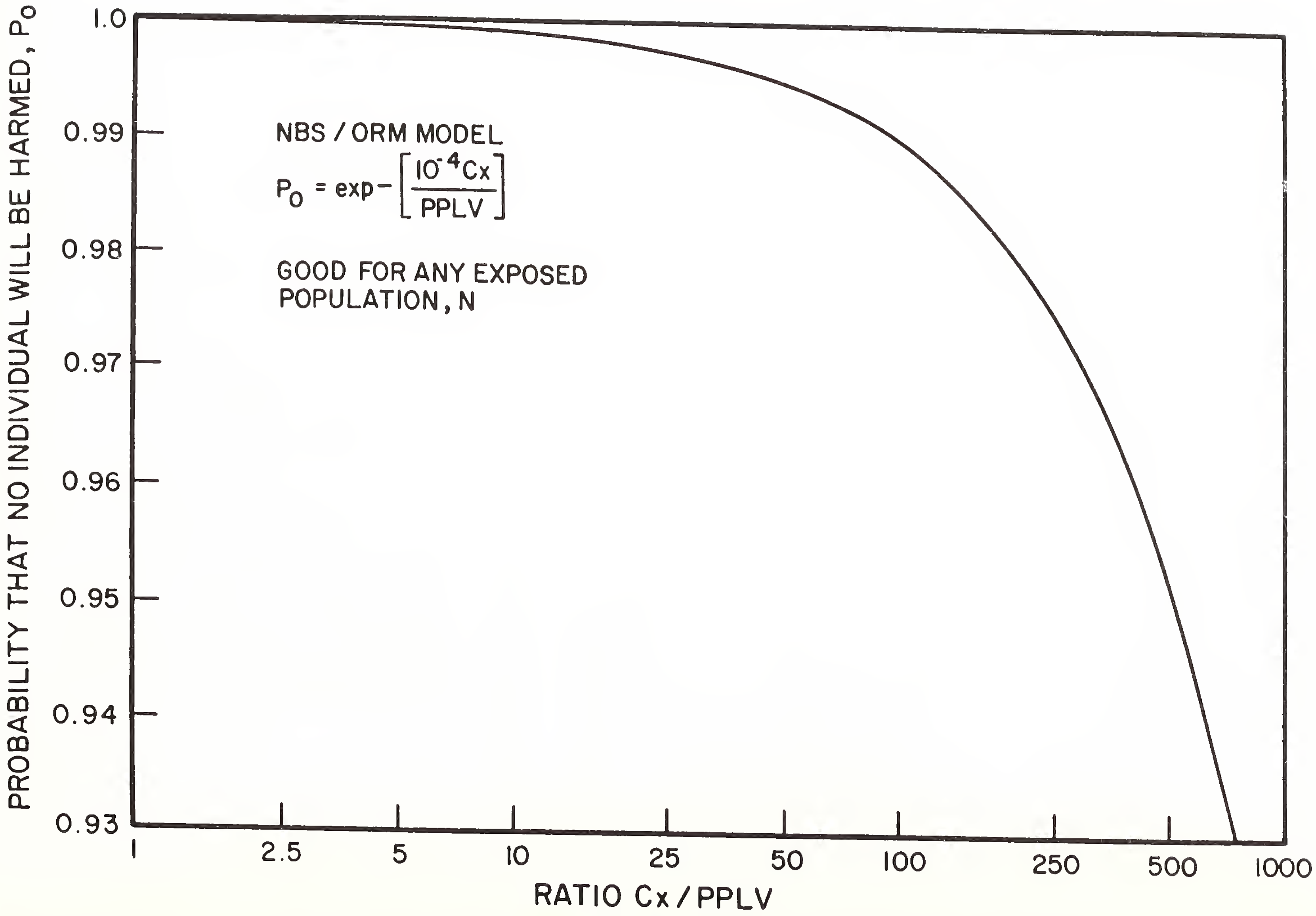


Figure VIII.4. Probability that no individual in an exposed population will be harmed by exposure to some concentration, C_x, of a potentially harmful chemical, x

$$\frac{\Delta P_o}{P_o} \left(\frac{10^{-4} C_x}{PPLV}\right) \left[\left(\frac{\Delta PPLV}{PPLV}\right)^2 + \left(\frac{\Delta C_x}{C_x}\right)^2\right]^{0.5} . \qquad (VIII-15)$$

This relationship indicates that even if PPLV and the measured Cx are both in error by a factor of 5, i.e., relative errors of 500 percent, then

$$\frac{\Delta P_o}{P_o} = \left(\frac{10^{-4} C_x}{PPLV}\right) (\sqrt{50}) = \frac{7.1 \times 10^{-4} C_x}{PPLV} . \qquad (VIII-16)$$

For a 1 percent relative error in P_o, C_x/PPLV is 14 and for a 10 percent relative error in P_o, this ratio is 140. A ratio of 1400 leads to a 100 percent uncertainty in P_o.

The PPLV concept and eq. (VIII-14) and (VIII-15) also serve to reduce the efforts and expenses associated with the determination of C_x since the need for many replicate analyses--to demonstrate with a high degree of confidence that a high percentage of the sample population is below the highest individual value of C_x measured--is obviated. Some four replicate analyses are probably sufficient to obtain a value of C_x having the required precision for use with eq. (VIII-14) and (VIII-15). If PPLV is taken as an upper limit, however, four replicates only provide a 70 percent certainty that 70 percent of all subsequent samples will fall below the highest value of concentration measured.

4) Computation of a PPLV leads to a direct statement of degree-of-hazard which depends on site specific criteria and is independent of population exposed. The "index" is simply the ratio of C_x to $(PPLV)_x$ where $(PPLV)_x$ is the lowest PPLV for all chemicals at the site.

One possible classification scheme is:

No hazard (Index 0): $1 \geq C_x/(PPLV)_x$

Minimal hazard (Index 1): $1 < C_x/(PPLV)_x \leq 14$

Minor hazard (Index 2): $14 < C_x/(PPLV)_x \leq 140$

Hazard (Index 3): $140 < C_x/(PPLV)_x \leq 700$

Major hazard (Index 4): $700 < C_x/(PPLV)_x \leq 1400$

Extreme hazard (Index 5): $C_x/(PPLV)_x > 1400$

For Index 0, $P_o < 0.9999$ with "worst case" $\Delta P_o/P_o$ of about 0.001.

For Index 1, $P_o < 0.999$ with worst case $\Delta P_o/P_o$ of 0.01

For Index 2, $P_o < 0.99$ with worst case $\Delta P_o/P_o$ of 0.1

For Index 3, $P_o < 0.95$ with worst case $\Delta P_o/P_o$ of 0.5

For Index 4, $P_o < 0.90$ with worst case $\Delta P_o/P_o$ of near unity

For Index 5, $P_o < 0.87$ and worst case $\Delta P_o/P_o$ is difficult to ascertain.

Thus, the extreme importance of accurate data in deducing PPLVs is made clear as are the requirements for accuracy in determining concentrations. Under these conditions, appropriate sampling methods, measurement methods, standard reference data and measurement standards can provide the technical foundation for dealing with the "cleanliness" questions associated with existing, proposed and even abandoned disposal sites. The work performed by NBS/ORM has contributed strongly to all of these requirements. (See Appendices V-IX and Publications List #'s 80, 90, 94, 113, 114, 118, 119).

The PPLV method and the W-E-T model are complementary. The W-E-T model or similar classification scheme can be used to suggest what wastes might be dealt with and by what technology, e.g., landfill, chemical treatment, incineration on land or at sea. After this rough classification, the PPLV method can be applied to the particular site in question in order to ascertain how cleanliness can be maintained and how the site monitoring system is to operate. The W-E-T model is primarily an economic tool having a crude hazard classification scheme attached, while the PPLV method is capable of providing good local estimates of hazard, once the W-E-T model has suggested an appropriate technology and cost for a given waste stream or coordination of waste streams. Taken together, the W-E-T model or similar scheme and the PPLV method can provide a powerful tool for dealing with many of the economic, scientific and technical issues relating to risks associated with treatment, storage and disposal of potentially hazardous wastes. But recovery, recycling and reuse of potentially hazardous waste streams can provide a better alternative if such recycling is technically feasible and can compete in an economic sense with other alternatives.

VIII.10. NBS/ORM Efforts Concerning Recycling of Potentially Hazardous Wastes

NBS/ORM initiated one pilot study involving the technical issues associated with the deoiling and subsequent recycling of steel industry mill-scale wastes. NBS/ORM personnel also served as technical reviewers for a DoC/EDA sponsored study dealing with characterization and recycling of electric furnace dusts. In addition, NBS/ORM examined some of the economic issues affecting the recycling of hazardous discards; the goal of this work was to provide a general model, which could be adopted on a state or regional basis, to indicate probable economic outcomes of certain hazardous waste management options. These activities were accomplished in partial fulfillment of the mandates of Sections 5002, 5003 and 5004 of RCRA.

VIII.10.a. Pilot Study of Steel Industry Mill-Scales

Representatives of the steel industry acting under the aegis of the American Iron and Steel Institute (AISI) approached NBS/ORM in early 1981 to propose that NBS/ORM and the steel industry cooperate in a recycling project. Specifically, the recovery of metal units and energy from oily general steel making wastes and/or recovery regeneration of NNO_3/HF pickling media from stainless steel operations were the two areas suggested. NBS/ORM saw an opportunity to increase recycling of the metal units but also to provide a use or market for waste or recycled solvents. Hence, NBS/ORM agreed to undertake a cooperative pilot project concerning deoiling of mill-scales and sludges providing that waste or recycled solvents be used as the deoiling medium. The steel industry representatives agreed to this condition and appointed a liaison group to act through the AISI.

The goals of the pilot project were to:

1) Evaluate the technical feasibility of existing and new methods for removing hydrocarbons from oil-containing steel plant sludges to render an iron-containing material suitable for recycling.

2) Determine the most suitable methods for recovering the hydrocarbon values in the waste, either as fuel value or as reclaimed oil.

These goals were selected because various iron containing solid wastes are generated in steel which contain hydrocarbons. The iron content of some of these substances is significant and could readily be recycled directly into steelmaking operations:

	Iron Content %	Hydrocarbon Content %	Water Content %
Mill Scale	60-75	0.01->1.0	2-5
Hot-Rolling-Mill Sludges	60-70	5-30	21-58
Cold-Mill Sludges	-	2-7	81-88
Waste-Water-Treatment Sludges	30-44	2-8	40-78

The "low-hydrocarbon" materials, such as mill scale, are normally recycled to the blast furnaces and sinter plant (if available). At times, some plants have added the fine mill sludges to the sinter-plant feed also. The use of the hydrocarbon-containing solids in sintering, however, results in a large portion of the hydrocarbons vaporizing in the sinter bed and reporting to the off-gases. These vaporized hydrocarbons either cause noncompliance with air-pollution opacity regulations, if electrostatic precipitators are used, or require the installation of expensive scrubbers involving complex water-treatment systems.

At present, most of the "oily sludges" are disposed of in landfill operations. Because of the physical nature of the sludges, special methods must be used prior to or after landfilling--slurries are disposed of in lagoons, which may require treatment of the leachate; filter or centrifuge cakes require blending with solid materials such as slag before above-ground disposal. Disposal costs have risen in response to regulations imposed by Federal and state authorities concerning land disposal of hazardous wastes. Since the domestic steel industry produces about three million tons per year of these hydrocarbon bearing materials, estimates of marginal cost increases due to increased disposal fees range from $50 million to $300 million annually. In addition, iron units which could be recovered if the wastes were treated to remove the objectionable constituents--the hydrocarbons and in some cases, residual metals--are being discarded.

Methods for treating oil-contaminated wastes include incineration, evaporation, and solvent washing. These techniques are best applied to mill scale because of its normally large particle size and comparatively low oil content. Because of the high oil content and fine size-consist of the oily sludges, they are difficult and expensive to deoil using incineration; and, at this time, little work has been done on solvent washing of these sludges. Therefore, testing of solvent-washing techniques is required to determine whether it is feasible to treat these sludges economically.

The NBS/ORM pilot project concentrated on the problems associated with the recycling of mill scale. Mill scale is the material that flakes off steel during the rolling process in the manufacture of shaped products (such as sheet steel or I-beams). The scale would be valuable as a raw material to be reused in making more steel but it is contaminated by lubricant used on the rollers. The oily residue may comprise from 0.5 to 5 percent of the mass of the mill scale and must be removed before it can be used for the ore-preparing sintering process. Sintering is the high-temperature process where ore, coal, lime, and possibly mill scale are combined at dull red heat prior to firing in the blast furnace. Presently, large quantities of mill scale can not be added because of explosions of the volatilized lubricant residue in the high-temperature process. Thus, it is important to find a suitable method for de-oiling mill scale.

In order to characterize the lubricant residue in mill scale, a Soxhlet extraction was done with a volatile solvent and the extract, was evaporated down to an oily residue. Soxhlet extraction provides the basis for a simple laboratory method to determine oil content before and after cleanup. The system is cyclic, operates in a virtually closed manner and the extracting solvent can be used almost indefinitely. Secondly, any one of a number of readily available solvents can be used for deoiling. Finally, the paper thimble used to contain the sample in the Soxhlet extractor provides a very convenient means for estimating completeness of extraction and for determining weight loss.

A study was made of a Freon 113 extract of mill scale and of the unused mill lubricant by gel-permeation chromatography (GPC). This analytical technique provided information about the molecular weight fractions of the samples. In this work, a polystyrene column with a 100 pore size was used with toluene as the flowing solvent. Molecules that are smaller than the pore size can diffuse into the stagnant solvent of the gel; whereas larger molecules will not, and thus will be carried more rapidly by the flowing solvent. Large molecules will elute from the column first followed by progressively smaller molecules. Although the separation mechanism is based on molecular size, this mechanism is linearly related to the molecular weight for similar materials.

Some general observations can be made about the chemical properties of the lubricants and mill scale extracts based on the GPC/RI data. The mill lubricants are characterized by very prominent aromatic hydrocarbon fractions of high (>500 amu) and low (100-400 amu) molecular weight. There is also a large aliphatic hydrocarbon fraction in the moderate (400-500 amu) molecular weight range. By contrast, the mill scale extracts are characterized by a much smaller amount of the high molecular weight aromatic fraction and only a moderate amount of the low molecular weight aromatic compounds. The amount of the moderate molecular weight aliphatic hydrocarbons found in the mill scale is similar to the amount found in the original lubricant.

The mill rolling process would be expected to produce some chemical and physical changes in the mill lubricants. The combination of the high temperature (red heat) contact with the possibly catalytic steel surface is likely to promote "cracking" of some of the high molecular weight compounds, and this effect is evident in the mill scale extract. Some of the low molecular weight compounds are evidently volatilized to the atmosphere or are carried off in the rolling water wash, and thus comprise a smaller fraction in the extract, relative to the original lubricant. The most predominant fraction of the extract is the aliphatic fraction of molecular weight 400-500 amu. These groups of compounds seem to be little changed by the rolling process. This knowledge should be of benefit in choosing the most efficient type of solvent for de-oiling mill scale. Recent work involved the comparison of several solvents of differing polarity. Four solvents were evaluated: hexane (least polar) < freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane) < methylisobutylketone < methylethylketone (most polar). The weight loss of the mill scale was measured and a GPC/RI molecular weight characterization was made on each.

The basic conclusions of the pilot study are:

Oil Recovery Experiment:

- Solvents of moderate polarity (methyl isobutyl ketone) gave the highest oil recovery efficiency.

Gel Permeation Liquid Chromatography:

- High molecular weight aromatics are probably not extracted well by any of the solvents in the low temperature Soxhlet extraction.
- All solvents gave good recovery of all aliphatics and moderate molecular weight aromatics.
- Low molecular weight aromatics are proportionally depleted in the extracts relative to the lubricants.
- Low molecular weight aliphatics are proportionally increased in the extracts compared to the lubricants (complete details are to be found in Publications List #115 - Appendix XV).

VIII.10.b. Characterization of Electric Furnace Dusts

AISI indicated to representatives of the Department of Commerce (DoC) that electric furnace dusts were also a major problem with respect to increasing costs of disposal. These dusts had been declared hazardous wastes. Thus, the steel industry faced huge marginal cost increases for disposal. The Economic Development Administration sponsored a study by Lehigh University which was meant to:

- Characterize the dust particles;
- Investigate chemical extraction and physical separation methods for the dusts;
- Determine the mechanism of dust formation; and
- Increase recovery and recycling of the dusts.

The electric-furnace utilizes nearly 100 percent scrap for its charge. Hence, any reduction in the output of electric furnace steelmaking could seriously impair markets for scrap iron. Thus, NBS/ORM had an interest in both the recycling possibilities for the dusts and the potential adverse effect on the scrap iron market. NBS/ORM personnel were associated with this DoC project as technical advisors and reviewers.

The electric furnace process is comprised of three major phases: the melting of metallic ferrous raw materials, the refining of the melt to remove unwanted tramp elements, and the final deoxidation and adjustment of composition. In many modern installations, the refining and deoxidation steps are completed in a separate vessel such as a ladle, the electric furnace being used only to melt the charge and preheat it to refining temperature.

The process may be either acid or basic depending on the nature of the refractories that contact the bath and the slag. The basic process, in which the basic oxides lime and magnesia predominate in the refractories and refining slag, is used in most large furnaces. The acid process, in which silica is the predominant oxide is found mostly in foundries. The nature of the wastes depends on the slag.

An electric furnace heat is begun by filling the furnace with scrap. The scrap comprises a complete array of factory trimmings and obsolete or worn out steel products. The impurities to be removed with the melt vary with the scrap. For example, galvanized steel introduces zinc; terne plate-lead; tin-plate-tin, and porcelain enamel may bring in antimony and several other elements. Rusty structural steel from an industrial environment may be extra high in sulfur while case iron is high in both sulfur and phosphorus. Depending on the final destination of the steel heat, there may be unwanted alloying elements such as copper, nickel, chromium, molybdenum, titanium and others. The presence of moisture in any form such as hydrated rust, is a source of detrimental hydrogen which is unwanted and must be removed.

The object of the melter is to convert the scrap into a homogeneous liquid, remove the unwanted elements, and adjust the composition to specified levels. The melt is then poured into molds where it solidifies into a form for subsequent processing.

The impurities and a portion of the desirable elements removed from the steel are supposed to be collected in the slag which has been prepared for this purpose. However, portions of the steel and the slag may form a cloud of dust and fume in the gases over the melt and its slag cover. The dirty escaping gases must be cleaned by one or a combination of processes including an electrostatic cleaner, a high-energy scrubber or a baghouse.

During the initial meltdown period considerable particulate matter is emitted. This material is most likely comprised of oxides of iron and other metals, with some smoke from combustible matter. As melting proceeds the slag begins to form and cover the melt. The arcs become more stable and emission of particulate may subside to some degree. Moreover, as the slag cover forms, the nature of the particulate emission will change.

In cases where a large amount of the lower grades of scrap is used, the initial particulate will probably contain a large amount of zinc from galvanized steel. Several other changes in composition may occur and these vary with the type of steel being melted and the method by which the melt is refined. Approximately 30 pounds of dust are created per ton of raw steel.

Several problems are associated with electric furnace dusts and sludges with respect to their potential for recycle or reuse. A few of these problems are:

a) Zinc, lead, and alkali elements in the dust carry through the sinter plant and into the blast furnace causing blast furnace operating difficulties (e.g., scaffolding and premature lining failure).

b) The very fine particulates create handling problems.

c) The iron content is highly variable and too low for reprocessing.

d) The amount of dust generated in a single steelmaking facility is usually too small to support a viable recovery facility.

The main results of the DoC/EDA sponsored Lehigh work are as follows:

The study of the mechanism of formation yielded several concrete suggestions for the reduction of the amount of dust produced with an attendant conservation of resources; namely

1) Take steps to minimize direct entrainment of additives in the furnace atmosphere as fine particles.

2) Reduce the total rate of gas flow through the furnace first by making the furnace more air-tight and, second, by keeping the gas bubbling rate through the bath to an absolute minimum.

3) Minimize the overall temperature in the furnace throughout a given heat combined with a slight increase in the duration of the heat.

4) Apply some form of enrichment or separation scheme to the particulates when the amount can no longer be reduced and, therefore, must be discharged from a given electric arc furnace.

Arc furnace dusts from stainless and specialty steelmaking are being treated by recycling techniques such as in-plant greenballing and recycling to the furnace, or are being sent to a centralized processing plant to be converted to a master alloy of controlled composition. Because of the use of a better grade of charge materials in the manufacture of these highly alloyed products, there is much less potential for recovering zinc, lead and cadmium.

The most likely outlets for the recovery of nonferrous values from carbon and low-alloy steel dusts are the existing smelters. The source of dust should be close to an existing smelter, and the dust should have a high zinc content (over 20 percent). Recycling processes will be needed to concentrate the zinc, lead, and cadmium to a sufficient degree to make them attractive to a smelter.

VIII.11. Economic Factors Affecting Recycling of Potentially Hazardous Wastes

For any region, the following data are required in order to determine the economic trade-offs associated with disposal and/or recycling options for potentially hazardous discards:

1) Determine what chemicals or mixes of chemicals are discarded.

2) Determine present fate of such chemical discards.

3) Determine how to assess and characterize such discards for potential hazards to humans and the environment (see, for example, the California Characterization and Assessment System for Hazardous and Extremely Hazardous Wastes)

4) Determine costs associated with disposal of chemical discards.

5) Assess risks to humanity and the environment associated with disposal of chemical discards.

6) Forecast trends associated with costs and risks of land disposal or of rendering harmless chemical discards which are judged as hazardous.

7) Determine what chemicals local industry, government and schools are using as feedstocks or reagents.

8) Establish "live" data bank.

9) Establish liaison with chemical production factors in order to attempt to classify discard stream in order to provide optimum fractions for recycling.

10) Determine technology needs, if any, to provide optimum fractions for recycling to meet local or regional markets as well as environmental and/or economic constraints.

11) Interact with State and local officials to provide optimal climate for collection, transport and recycling of chemical discards.

12) Carry out economic forecasting and trade-off analysis of recycling vs. disposal option in the region.

13) Attempt input-output analysis to check effects on individual SIC coded industries.

14) Establish mechanism to maintain the system.

VIII.11.a. Econometric Methodology Development

In order to deal with these 14 points NBS/ORM, in partial fulfillment of the mandates of sections 5003(2) and 5004 of RCRA, chose to examine opportunities for economic development and resource recovery in terms of hazardous waste management in the Great Lakes Region. Complying with regulations or guidelines for hazardous waste management usually involves altering the process used, or directing the wastes through disposal routes which differ from those which have been traditionally used. This imposes on the industries concerned either high operating costs or higher capital costs. They are typically direct costs to the enterprise concerned, and are likely to be partly absorbed by the enterprise, and partly passed on to the purchasers of the products. These costs will, therefore, affect the profitability of the industry. Some companies, operating on a small-scale, with obsolete plants and equipment, and small operating profits, may find their existence threatened by these regulations. Throughout FY 1981, the Great Lakes Basin Commission (GLBC) conducted a study meant to develop methodologies for projecting the economic development effects of hazardous waste management and to assess the potential for resource recovery of material from selected waste streams: steel manufacturing, electroplating, and paint manufacturing. This study commenced September 1980 and was scheduled for completion by May 1982. However, the Great Lakes Basin Commission expired as of September, 1981. Since then the Michigan Department of Commerce sought and received from Office of Recycled Materials a new grant initiative to complete this study and to explore implementation options. The Michigan Department of Commerce retained original project staff; consequently, the study was completed by 1982. The Michigan Department of Natural Resources assisted as technical advisers to the project. (See Publications List #95 for complete report).

This study had two major purposes. The first was to develop methodologies that would assess the economic impacts associated with hazardous waste management in the Great Lakes region. The second was to develop methodologies that could evaluate the economic potential for resource recovery in hazardous waste management. In conducting the study these two purposes often were difficult to separate.

The objective was to develop methodologies which could be applied in future studies to any industries that generate hazardous wastes. This is not to say that this study did not produce any results other than a package of methodologies. To determine if the methodologies would be feasible and efficient, they were tested by applying them to three case study industries chosen at the outset of the study. As a result of these tests, conclusions regarding the economic impacts of hazardous waste management and the potential for resource recovery were obtained, if only for these industries. However, it must be emphasized that the primary purpose was the development of methodologies.

The study was primarily economic in nature. The methodologies were intended to analyze the economics of hazardous waste management, and that intention was followed. However, economics is only as good as the data which it applies, and it became apparent at the outset that any methodology must first examine the technical parameters of the problem. Therefore, many of the methodologies incorporate a great deal of technical information regarding hazardous waste characteristics and the systems for management of the wastes.

The development of a methodology to assess the economic impact associated with hazardous waste management involved several tasks. Some of the tasks were intended to provide background data, and others to develop major components of the methodology. For example, before the economic impact on industries within the region could be evaluated, the costs of managing hazardous wastes had to be determined. Therefore, a methodology was developed to determine the least cost options for managing wastes within particular industries. The information from these models was then applied to a methodology to determine the financial impact on individual companies. The results of the financial impact model were then used to predict impacts within a state or region, based on a regional impact methodology that was developed. The results of the economic methodology were also used to test a methodology which assesses whether firms are likely to relocate as a result of hazardous waste management costs.

The methodology for assessing the potential for resource recovery proceeded in a similar way. After conducting tasks which looked at the technical and marketing aspects of resource recovery, a methodology was developed which determines all of the factors that must be analyzed to evaluate the potential for resource recovery. The actual economic potential was analyzed as part of the economic impact methodology. To determine whether resource recovery would have even greater potential if various financial incentives were provided, a methodology was developed and tested using the results of the economic model.

The absence of good data is a chronic problem in economic studies, and this study was no exception. The major deficiency of data was for the steel industry, one of the case study industries selected. There was very little economic information regarding hazardous waste management in this industry, in part because the costs had never been evaluated to the degree of precision needed for this study, and in part because the required data were often proprietary. As a result, the steel industry was only analyzed where the data allowed.

There were also problems with the financial data required for the financial impact methodology. The model that was developed required some data that were not available through Dun and Bradstreet reports. The study was able to work around these problems, but the results are not as robust as had been hoped. More problematic was the inability to acquire financial information for the same firms for which technical data were available. This necessitated averaging, which is never as accurate as analyses based on individual data.

Another problem was regulatory in nature. One of the case study industries selected was paint manufacturing. At the time the industry was selected, many of its wastes were listed as hazardous. Subsequently, the U.S. Environmetal Protection Agency delisted many of the paint wastes, but the study was too far along to select another industry. Instead, the study focused on solvents generated by this industry, which are hazardous, and provided an excellent case for the resource recovery methodology.

Since it was too costly to analyze all industries that generate hazardous wastes, and because the study had a methodological focus, a case study approach was taken. A methodology was developed which would select three industries that best met a number of criteria that reflected the objectives of the study. The criteria included such factors as resource recovery potential in the industry and likelihood of economic impact from hazardous waste regulations. After reviewing information on 25 industries that generate hazardous wastes and ranking them according to each criterion, the three industries that ranked the highest were electroplating, paint manufacturing, and the steel industry. A lack of information on hazardous waste management costs in the steel industry eventually precluded a complete analysis of this industry, and a delisting of many of the wastes in the paint industry narrowed the scope of this industry's analysis to solvent recovery.

Once the case study industries had been selected, a technical review of each industry was prepared. This review identified each of the hazardous wastes generated and current practices to treat and dispose of these wastes. In addition, a literature review and contacts with engineers in the industries revealed alternative treatment/disposal and recovery technologies that may be technically and economically feasible. A summary of hazardous waste regulations affecting each case study industry was also prepared.

The study required information on the cost of treating or disposing of hazardous wastes in the region. Therefore a survey of all off-site landfills, treatment facilities, incinerators, and deep-well injection sites was undertaken. It identified current charges, and estimated increases that would result from compliance with federal Resource Conservation and Recovery Act (RCRA) regulations. The charges varied widely for each type of facility, depending on the hazardous waste being handled. Landfills were expected to incur the highest regulatory costs, but the greatest increase in charges would occur at treatment facilities. Increasing demand for treatment and disposal services is likely to result in charges somewhat higher than the level necessary to recover compliance costs.

Once the requisite background information had been collected, models of the economics of hazardous waste management were developed.

Their purpose was to determine the most economically efficient waste management alternative, given various technical constraints. Two models were developed; one for the electroplating industry and the other analyzing options for solvent recovery. Both models were based on constrained economic optimization methodology.

The computer model for analyzing the electroplating industry compared the cost of five alternative treatment and resource recovery technologies for 24 electroplating shops in the Great Lakes region. The cost and selection of management options varied significantly among firms depending on technical parameters such as water use and metal concentrations. The annual costs to a plating shop were quite high, ranging from $10,000 per year for a very small operation to $250,000 per year for the largest company. Under the "most realistic" scenario only a few of the firms analyzed found one of the resource recovery technologies to be their least cost option.

A sensitivity analysis of the results of the electroplating model was conducted to determine what kind of financial incentives would induce greater adoption of resource recovery technologies. The incentive with the greatest effect on increasing the use of resource recovery was an investment tax credit. An investment tax credit for recovery equipment of 25 percent resulted in 25 percent more firms choosing resource recovery as their least cost option. Accelerated depreciation and a 10 percent tax credit on recovered materials had very little effect. However, if the interest rate charges for loans on resource recovery equipment was 10 percent lower than the borrowing rate on conventional treatment equipment, the number of firms opting for resource recovery increased 24 percent .

The model for analyzing the economics of solvent recovery compared the cost of off-site disposal or incineration with off-site recovery of waste solvents and with recovery at the plant site. In all cases, off-site recovery of solvents resulted in substantial savings over disposal or incineration unless a substantial energy credit was paid for burning waste solvents. The cost of on-site solvent recovery varied significantly between large and small firms. In most cases, on-site recovery was justified for larger firms, and in some cases on-site recovery was less costly than off-site recovery for smaller firms.

In order to determine the economic impact of hazardous waste management costs, a computer program for a financial impact model was developed. This model analyzed the effect that waste management costs generated by the electroplating model would have on key financial indicators of firms in the electroplating industry. The model makes various assumptions regarding demand and supply elasticities, and then determines how the balance sheets and income statements change as waste management costs are incurred. The model results indicated that there are likely to be substantial economic impacts on small-to medium-sized firms under all but the most optimistic scenario.

The results of the financial impact model were the basis for testing a regional impact methodology developed in this study. This methodology is designed to predict the aggregate economic impact on a state or region resulting from changes in employment and income in an industry that is impacted by hazardous waste management costs. Various income and employment multipliers indicate how losses in one industry translate into greater impacts throughout the regional economy. The methodology was applied to the results of the financial impact model under the assumption that 15 percent of the electroplating shops in Michigan would be forced to close as a result of hazardous waste management costs. Under this scenario, income losses would be between 29 and 47 million dollars, and between 1,000 and 2,000 jobs would be lost.

The study also developed a methodology to predict whether companies that generate hazardous wastes would be likely to relocate closer to treatment and disposal facilities to reduce transportation and disposal costs. The methodology weighs the transportation and disposal cost savings against changes in other locational costs such as product transportation and labor costs. Sensitivity analysis of the electroplating model increased the distance wastes would be shipped to 500 miles and the cost of disposal to $3.00 per gallon. These changes increased annual costs by an average of 30 percent. While these changes are significant, they are unlikely to induce firms to relocate. A more likely effect of these cost increases is that firms will adopt resource recovery technologies that lower the volume of waste that must be disposed.

The final methodology developed for the study was a detailed approach to evaluating the feasibility of resource recovery. It examines each of the factors that must be evaluated if a hazardous waste is to be successfully marketed or recycled. The methodology begins with a complete analysis of a firm's hazardous waste stream and proceeds through an analysis of all of the technical, regulatory, marketing, and economic aspects that must be considered. Resource recovery is under-utilized in many industries because of a lack of information and resources to evaluate its potential.

Certain methodological conclusions can be made. At the same time, the methodologies were tested by applying them to hazardous waste management practices in three industries. Therefore, the study generated conclusions regarding economic impacts and the economic potential of resource recovery. Caution must be used if the results from a sample of three industries are to be generalized, but some conclusions would seem to be applicable to most industries that generate hazardous wastes.

The most important methodological conclusion that can be drawn is that the results depend quite heavily on precise specification of the technical, regulatory, and financial parameters. This outcome may seem obvious, but many studies rely on average values. This study has demonstrated that the use of averages may lead to erroneous conclusions. The Hazardous Waste Treatment Alternative

Analysis Model developed in this study generated results which varied greatly from firm to firm. Similarly, if the Financial Impact Model had used the average financial position of electroplating firms, it would have obscured the financial strain that hazardous waste management costs impose on many firms. Therefore, if these methodologies are to be applied to other industries, an effort should be made to secure the best data that are available.

The foregoing does not mean that the methodologies developed in this study are difficult to apply, or that they require reams of data. On the contrary, they are relatively straightforward and were designed to be used by private industry or government agencies that need information on economic impacts or resource recovery. Computer models were developed for the economic and financial analyses, but the methodologies could be applied with a hand calculator. This study computerized the models primarily because of the amount of sensitivity analysis that needed to be performed. The Financial Impact Model does require a great deal of financial data that is often difficult to obtain for smaller firms. To avoid the necessity of collecting all this data, two simpler models were developed that require much less data, with little reduction in accuracy.

The results indicate that resource recovery is an economically feasible alternative in many cases, and does have a great deal of potential, at least in the industries studied. In fact, resource recovery is probably being under-utilized because of a lack of information concerning markets for recovered products or its economic feasibility for in-plant recycling. The methodology developed to assess whether particular hazardous wastes can be recovered found that many firms were not aware of the marketability of particular wastestreams or how they could treat the wastes to increase their value. The methodology pointed out that the ability to determine whether a product can be recovered from hazardous wastes is often beyond the capability of smaller firms. For this reason, it is probably appropriate that industry trade associations provide the necessary information regarding resource recovery systems.

This study evaluated the private cost of resource recovery, excluding the potential savings associated with the liability issue. A few of the larger firms the study contacted had chosen to install resource recovery systems because they were concerned that off-site disposal might eventually lead to liability claims against the company. In this respect, the study undervalued the true savings associated with resource recovery.

No evaluation was made of the social costs of off-site disposal vs. resource recovery. Since resource recovery reduces the volume of hazardous materials that could potentially be exposed to the environment, resource recovery may impose lower social costs than other hazardous waste management techniques. Therefore, society may want to provide incentives for hazardous waste generators to use resource recovery. This study considered several financial incentives that could be used, and evaluated how they would increase the use of resource recovery in the electroplating industry.

The incentive that would have the greatest effect on lowering the cost of resource recovery was an investment tax credit applied against the capital costs of the system. An investment tax credit of 25 percent increased the number of firms choosing resource recovery over conventional techniques by 25 percent. Currently, the investment tax credit applies equally to resource recovery and conventional systems. Very low interest rates also tend to favor resource recovery, and a 10 percent difference in the interest rate charged on loans for resource recovery and conventional systems had a significant effect. Accelerated depreciation on recovery systems was found to have a minor impact, as did a 10% tax credit for recovered materials. Even though these incentives were applied to the electroplating industry, the relative effect of the incentives would be much the same in any industry.

The economic impact portion only focused on the case study industries, so no general conclusions on total impact can be made. However, if the results obtained from the case study industries are indicative, there may be fairly significant impacts on small firms that generate hazardous wastes. The cost of treating and disposing of hazardous wastes in the electroplating industry were found to be a significant proportion of total costs for small and medium sized firms. The Financial Impact Model showed a dramatic worsening in the key financial ratios of many of these firms, and in several cases hazardous waste costs made the difference between a profit and a loss. If as many as 15 percent of the electroplating shops in Michigan were to close as a result of these costs, the loss of income to the state would approach $50 million.

The other economic impact issue concerns the availability of hazardous waste treatment and disposal facilities in the region. Currently, many generators must ship their wastes out of state for disposal, which is quite costly. The Hazardous Waste Treatment Alternative Analysis Model demonstrated that the cost of hazardous waste management increased by an average of 30 percent when the transportation distance increased from 25 miles to 500 miles. While the locational impact methodology suggested that this increase would not be great enough to induce firms to relocate, it does a significant cost burden on hazardous waste generators. A scarcity of hazardous waste facilities will also increase disposal charges. Therefore, efforts by the states to overcome opposition to the siting of new facilities should be increased to minimize the already substantial economic cost imposed on firms that generate hazardous wastes.

The methodologies developed and utilized in this study are transferable to other regions in the United States for industries which are facing problems of dealing with hazardous wastes in the most economically efficient manner. Hence, each of the required 14 points can be taken into account for whatever region is chosen.

VIII.12. Summary of Requirements

The following four parameters are crucial to the technical foundation for any program:

a) Qualitative analysis of potentially hazardous wastes: organic and/or inorganic and, mixed or unmixed.

b) Measurement methods to determine the concentration of potentially hazardous wastes. This requirement implies development of a measurement assurance program so that the results from complex and expensive tests can be translated, on a controlled basis, to less complex and less expensive tests having similar precision and accuracy.

c) Determination of the concentrations of potentially hazardous wastes moving in a specific ecosystem as a function of time.

d) Estimation of the cumulative probability for harm associated with specific substances (and possibly specific sites) at some point in time in relation to a given population and/or ecosystem.

An approach to these issues and provisions for consistent Federal and State regulatory stances are desperately needed. Cooperation between all affected parties is needed in order to achieve a fair and equitable means of dealing with the technical, economic and institutional challenges posed by the need to dispose of so-called hazardous wastes.

A framework of actions which might be undertaken on behalf of all parties-of-interest includes the following:

- Review and analyze the various definitions of hazardous wastes and procedures and methods for differentiating such wastes, e.g., composition and characteristics, currently utilized by Federal agencies, State and local government, and affected industrial operators.

- Identify sources of data related to the generation, transport, processing, recycling, disposal, and health-related affects of potentially hazardous discards; critically evaluate these data.

- Identify and evaluate the technical methods and procedures for determining composition, characteristics, mobility, and health-related effects of hazardous wastes via identification and evaluation of test methods and procedures allowing for a statistically valid analysis of the data.

- Analyze current and proposed State and Federal legislation/regulation with emphasis on similarities and differences between State and Federal technical and economic requirements.

- Compare Federal and State insurance requirements for hazardous waste disposal facilities, including actual relationships in terms of applicable laws and appropriate measures and definitions of liability.

- Compile and determine on a State-by-State basis, the estimated costs associated with implementation of potential regulatory strategies.

- Develop methods to estimate the economic burden placed upon the regulator as well as the regulated community.

- Examine institutional considerations.

- Evaluate the cost-effectiveness of achieving an implementation strategy which will assure equivalency with existing and proposed Federal regulations and which provides for State-to-State consistency with such regulations.

A number of parties, e.g., ASTM Committee D34 on Waste Disposal and various Federal agencies, have addressed themselves to some of these issues. The Office of Recycled Materials of the National Bureau of Standards, U.S. Department of Commerce, studied the possibility for correlating and collating existing information and developing new information as well except that no health related issues were to be examined. Some of these NBS/ORM activities have already been discussed; others follow.

VIII.13. State Measurement Needs

In an effort to determine the ability of the states to provide appropriate measurement technology and methodology, NBS/ORM issued a grant to the Association of State and Territorial Solid Waste Management Officials (ASTSWMO). This Association is comprised of State officials responsible for the planning and implementation of State resource recovery and hazardous waste management programs under the Resource Conservation and Recovery Act of 1976, as amended. Forty-three States are represented by the organization.

The Association's Resource Recovery Committee considered the following questions:

1) Does the State have adequate laboratory support staff, equipment, and resources or the services of a private contractor to perform RCRA-related measurement activities?

2) What are State laboratory equipment holdings?

3) Are the laboratories certified? Do they have a quality assurance program?

4) Is there adequate laboratory and field protective equipment and clothing?

5) What types of technical assistance do laboratory and field personnel need and from which entities?

6) What are the overall prioritized needs in support of implementing the technical requirements under RCRA?

The Association Committee prepared profiles of seven States' individual responses to the above cited inquiries. Those States were Oklahoma, Texas, Louisiana, Mississippi, Virginia, New York and Pennsylvania.

The Committee concluded that even though State programs vary in stringency of regulatory requirements, State measurement needs are similar in hazardous waste. However, Subtitle D resource recovery measurement needs, while identified, do not exhibit the same level of priority associated with Subtitle C program. Nevertheless, standard analytical methods, protocols, and procedures specified in State regulations match those methods cited in Federal criteria. Development of standard laboratory and field methods for sampling and analyses as well as standard reference data is required. The lack of availability for such measurement tools is severely impeding national consistency on a State-to-State basis, timely program implementation, and worker protection and safety. Consequently, a formal operating procedures manual is necessary to assure not only State-to-State programmatic and enforcement consistency, but also in intra-State field and functional laboratory activities. A standard laboratory certification quality assurance program does not exist and will be helpful in attaining State-to-State consistency. Lastly, training programs and technical assistance for laboratory and field personnel are inadequate at State level.

The Report itself runs to 9 volumes (Publications List #'s 82-89 and 121) and consists of the following sub-parts:

o Part I: Final Report and Executive Summary: State summary charts containing definitions of hazardous waste, measurement parameters, laboratory needs, and available training programs; Conclusions and Recommendations

o Part II: State Profiles (Texas, Louisiana, Oklahoma, New York, Pennsylvania, Mississippi, Virginia): Solid waste, hazardous waste and resource recovery program objectives; State agency organizational make-up; resources and manpower; selected regulations; data from field visits on laboratory capability; other appropriate documentation.

o Part III: Analytical Operations Procedure Manual Model: A cohesive technical framework and outline of tools necessary to augment States' hazardous waste program based on experience and guidance of State of Louisiana.

In addition, NBS/ORM prepared a summary of the present situation in the several states with regard to control of hazardous wastes. This survey is included as Appendix X. Based upon these findings the immediate outlook is as follows:

> Despite funding shortages and dilemmas, states will continue to assume, administer, and expand their respective hazardous wastes programs. Funding will be supported through combination of fees and appropriations. By 1984, the majority of states will have authorized hazardous waste programs in place. Concurrently, a result of federal funding and staff reductions and completion of state assumption process, the direct involvement of federal regulatory agency can be anticipated to lessen. Implementation issues (e.g., state-to-state consistency) will come to the fore. Resolution at the regional level will be attempted. Technical difficulties will arise should states measurements needs not be addressed. Debate on perpetual care and victim compensation will be aired in Congressional and State legislative community as part of the regulated community need be apprised of the legislative, technical and economic issues.

VIII.14. NBS/ORM Participation in the OECD Study Concerning Control of Hazardous Wastes

The Waste Management Policy Group (WMPG) of the OECD came to the conclusion in late 1980 that the economic dimensions of hazardous waste management were not well understood. In fact, the international aspects were essentially not understood at all. At that time, the GLBC/State of Michigan study sponsored by NBS/ORM had just begun. Since similar basic issues faced a community of industrial partners as faced a group of industrialized states within the U.S. the WMPG adapted certain portions of the NBS/ORM project to the needs of the OECD. The WMPG also added new goals. The major issues are concerned with the fact that the hazardous waste regulations that have been implemented affect the cost of production of the companies concerned, and may affect the technology that is used. A country may not have the capacity to manage some wastes within its own boundaries, and they may have to be transported across national frontiers. The need to clean up and rectify sites where hazardous wastes have been tipped imposes costs either on regional authorities or upon private developers. Insurance and assurance for sites licensed to accept hazardous wastes may impose high costs on those companies or local authorities operating these sites.

The set of problems associated with hazardous waste management is extensive. In the area of basic data, it is necessary to have some general information regarding the regulatory environment, as well as the amount and nature of wastes generated and the expected increase in these flows in the future. The current capacity of the hazardous waste industry, the methods of treatment and disposal and their costs are also important parameters for any assessment of the issue.

The Waste Management Policy Group discussed these basic information needs as well as specific problem areas within the general topic of hazardous waste management, and arrived at a consensus on those areas which were to be included in the hazardous waste work program of the Group. These are:

1) the transport of wastes across frontiers, the quantity, the reasons for these flows, and the provisions made for them;

2) the costs to industries of complying with regulations, and the costs to the regulating agency of enforcing the regulations; and

3) the insurance and assurance of operations involving the storage, transport and disposal of hazardous wastes, and the liability for damage caused by inappropriate management at any stage.

For Item 1 above, the WMPG is compiling:

- the procedures that are followed to permit the transport of these wastes across national frontiers;
- the costs of transporting hazardous wastes over long distances; and
- the legal provisions covering liability for damage caused by spills of wastes during the transport or storage of wastes outside their country of origin.

The chief impact of the NBS/ORM results will be for Item 2 via the use of the methodology developed in the GLBC/State of Michigan study:

- to characterize the extra costs to be borne by enterprises which modify their processes;
- to evaluate disposal or storage costs under the requirements of specific regulations; and
- to identify particular industries where the burden of compliance costs may radically affect the viability of a significant proportion of the firms in the industry.

The OECD investigation will serve to indicate the usefulness of the NBS/ORM methodology in the international arena. Clearly, any problems in transferring the methods to cases other than the U.S. Great Lakes states will be identified and can be taken into account. Thus, the OECD efforts will provide a critical review and a further application of the NBS/ORM work in this area.

With regard to Item 3, insurance, assurance and liability, financial provisions to deal with costs of damages caused through accidents, occurring during any operation involving hazardous waste transport, storage or disposal, and through malpractice relating to any of these activities, are of concern primarily because traditional insurance markets are not currently able to provide insurance cover. There are three basic issues involved:

- the provision of liability insurance in case of accident;
- the determination of liability; and
- the provision of assurance to ensure proper hazardous waste disposal site operation, decommissioning, and post-closure maintenance.

NBS/ORM did a brief review of the technical issues associated with potential insurer risk and the requirements for the size of a reserve fund to prevent insurer bankruptcy. While the computation of probability for survival of such a fund is straightforward, uncertainties with respect to liability of parties and the extent of liability have not been resolved in the U.S. as of the fall of 1982. Therefore, insurance carriers are likely to move slowly and to be extremely risk adverse regarding third party liability insurance.

If the PPLV concept, with or without the extension according to eq. (VIII-14), achieves a measure of public acceptance, then some measurable basis for assessment of risk by the prospective insurer will be available. Until there is such a basis, insurance availability and rates if available are likely to remain in a state of flux.

IX. MARKETS FOR RECOVERED MATERIALS (SECTION 5003 OF RCRA)

IX.1. Congressional Mandate

Section 5003 of RCRA (42 USC 6953) placed three responsibilities on the Secretary of Commerce (See Section IV.(1) for exact wording).

1) Market surveys for recovered materials.
2) Identification of economic and technical--but not institutional--barriers to the use of recovered materials.
3) Actions to encourage the development of new uses for recovered materials.

These responsibilities were delegated to NBS/ORM in January, 1980 by means of an ammended Departmental Organization Order (10-1, Amendment 5, rescinded in October, 1982). A number of NBS/ORM activities in response to Subtitle E of RCRA served to partially fulfill requirements under more than one section, e.g., most of the activities concerned with potentially hazardous discards (See Section VIII). But Section 5003 clearly required some specific new projects to be initiated by NBS/ORM.

With regard to market surveys, a broad survey, national in scope, had been carried out in 1976 on behalf of the Congressional Office of Technology Assessment; this survey dealt only with recoverables from MSW (Materials and Energy from Municipal Solid Waste, OTA, Washington, DC 20510, 1979, Vol. II). The general conclusion was that markets were regional in nature, highly volatile and thus subject to very high risk for participants. More specific market surveys, e.g., state-wide tended to reproduce these results.

Hence, NBS/ORM was faced with the dilemma of devising a means to deal with market fluctuations in a dynamic fashion. Any direct market survey, whether national, regional or local was likely to be subject to rapid change, i.e., might be obsolete before published. But, valid techniques to sample markets needed to be developed.

NBS/ORM chose to commission one major regional market survey dealing with just one recovered material--wastepaper. This study was organized and carried through by the Bureau of Industrial Economics of DOC (BIE).

IX.2. Market Survey for Wastepaper in Four Southeastern States

Waste newspapers are a source of fiber for the manufacture of numerous paper and board products, and the main ingredient in cellulose insulation. Wastepaper dealers are the major suppliers, often relying on individuals, volunteer groups, institutions, and municipalities for collection. Because of the concentration of paper and board mills in the South, especially North and South Carolina, and Georgia, these states have a high demand for waste newspapers.

In the Fall of 1979, representatives of the industrial wastepaper community expressed concern that the future supply of waste newspapers (old news) may not increase sufficiently to prevent prices from rising sharply in the Southeast Atlantic States. The sources of this apprehension were the opening of a newsprint mill in Georgia that will need 150,000 tons of old newspapers per year, the increase in old news consumption by cellulose insulation mills in the region, and an apparent increase in exports of old news. In addition, concern was expressed regarding the possible adoption by some Florida counties of a "flow-control" ordinance. This would assign collected municipal solid waste to resource recovery facilities which would convert solid waste, including the paper content, to saleable energy, principally in the form of steam. The restrictive ordinance could obstruct the free market for waste newspapers by eliminating the potential for cooperative source separation programs with municipalities, deprive the wastepaper recovery firms of the waste newspapers they need to survive, and cut off the user mills from a source of raw material.

The BIE Study provided data on the markets for waste newspapers in North and South Carolina, Georgia, and Florida for the Office of Recycled Materials, National Bureau of Standards. It was not intended to promote one market over another or draw conclusions regarding whether or not a specific resource recovery facility should burn waste newspaper. The BIE report provides the best publically available marketing data on the subject in the four-state area.

IX.2.a. Survey Results

Supply and Demand

Data gathered through field interviews with wastepaper dealers, paper and board mills, and cellulose insulation manufacturers indicate that nearly 52 percent of the recoverable newsprint consumed in the survey states in 1980 was recycled to user mills or exported. This is far higher than the national recovery rate of about 23 percent. The potential supply of recoverable newsprint was 855,700 tons in the four-state region, of which 438,600 tons was recycled in 1980. Paper and board mills consumed 337,200 tons and cellulose insulation producers used 111,300 tons; exports accounted for 3,700 tons. This region's reported receipts of waste newspapers from outside the four states were about 10,000 tons. Florida was the largest supplier of waste newspaper and accounted for 60 percent of the potential supply. Georgia was the largest consuming state, using 70 percent of the recycled newspapers in the region, mainly in paper and board mills.

The survey data indicate strong growth in demand for waste newspapers. Consumption of old news by user mills in the survey region doubled between 1977 and 1980, reflecting the startup of a new paper mill. Projections made from survey interviews suggest an increase in consumption of 8.2 percent to 475,000 tons by 1982. Exports are expected to recover to 11,000 tons in 1982 after a sharp decline in 1980. The greatest area of uncertainty in future demand was in the cellulose insulation industry, which has experienced some disruption in recent years. The supply of waste newspapers should be adequate to meet any increase in demand, especially if prices increase.

With a recovery ratio of about 50 percent in 1980, the potential supply should not cause limitations due to any depletion of the volume of used newsprint available. Moreover, the survey data indicate that the supply of recycled newspapers is highly sensitive to prices; dealers believe they could get all the old news they need at a price of $2.00 per ton, compared with the price of about $1.50 per ton in 1980.

Dealers

- More than one-half of old news processed by wastepaper dealers is purchased at the dealer's place of business. The remaining volume comes almost equally from that purchased on contract and that recovered by company initiatives.
- Dealers obtain the old news primarily in their local areas, and sell it in a much larger area, often using rail transport for shipments to user mills. Transportation costs for dealers' receipts are carried by the seller, the user mills pay transportation costs for dealers' shipments.
- Price variations imply that there are marketing opportunities in developing special market arrangements and negotiating on price and specifications.
- Dealers must compete for sales with local groups and individuals who deliver old news directly to the manufacturers.

Paper and Board Mills

- Paper mills reported that price is the major factor controlling quantity supplied. A few firms reported purchases through formal contract arrangements.
- Paper manufacturers stated that technological improvements in wastepaper cleaning systems would encourage increased use of old news.

Cellulose Insulation Mills

- Most of the waste news consumed by cellulose insulation manufacturers in the survey region comes from Florida. Florida leads the other states in expected growth of shipments of cellulose insulation.
- Georgia was the largest producing state in the survey region. Cellulose insulation producers consumed 78,200 tons of newspapers in 1980, compared with 18,300 tons in the Carolinas and 14,700

tons in Florida. Firms in Georgia covered the largest radius to obtain supplies of old news.

(For complete details, see Publications List #91.)

NBS/ORM personnel maintained close contact with BIE while this survey was taken. We concluded at an early moment that a comprehensive set of market surveys for even just the recoverables from MSW would require about 44 studies comparable to the BIE effort. When other recyclables, e.g., solvents or other industrial materials were added, the requirements doubled. Not only was such an effort beyond the resources of NBS/ORM, but there was a strong possibility that many of the results might be obsolete by the time the work was completed.

IX.3. Resource Recovery Market Models

NBS/ORM chose to develop models which would aid decision makers in selecting resource recovery options. Models were developed for selecting appropriate municipal solid waste management and recovery options and for comparing the economic outcomes of selecting resource recovery for certain industrial wastes as opposed to other options, e.g., various forms of disposal. (See also Section VIII.11.a)

The general goal of this exercise was to identify options which would be economically efficient, Then the specific market situation required to fulfill the efficiency criterion as a function of time could be pinpointed. Thus, specific market effects on a specific plan could be deduced and the survey requirements would be reduced to estimating whether a satisfactory market existed or would exist to meet the predetermined--nearly optimal--plan.

IX.3.a. Evaluation Criteria for Mathematical Models

The question of how well a model might be used to represent the real world thus became of great interest to NBS/ORM personnel. For this reason, R. E. Chapman of the NBS Operations Research Division was asked to prepare a brief statement concerning the evaluation of models. According to Chapman, at the most basic level, one can define three topics which should be addressed in any model evaluation activity. The topics are:

1) appropriateness;
2) validation; and,
3) documentation.

In the discussion which follows, each of the terms will be defined. A brief description of how one would assess whether or not a particular model adequately covered the issue under consideration will also be presented.

IX.3.a.1. Appropriateness

Many modelers believe that the purpose of building models is to gain insight into how a particular process operates or to predict the future behavior of the system. In either case, the logical first step is to hypothesize a theoretical model of the process. At this stage, many simplifying assumptions are made regarding what is important or unimportant or what is controlled or uncontrolled. These decisions should be documented and carefully assessed because they govern the functional relationships which form the basis of an operational model. The appropriateness issue thus focuses on the structure of the abstract model which establishes the foundation upon which the rest of the modeling effort is based. If the abstract model is revealed to be seriously flawed, then the entire exercise of constructing and validating an operational model is likely to be of little use.

One way in which model appropriateness can be assessed is to survey recent technical advances in the field to see if some systematic development of a particular aspect of the problem is revealed. Agreement here should provide guidance regarding functional forms and serve to warn against potential pitfalls which confronted other researchers. In the absence of adequate technical documentation, it would seem advisable that some pooling of ideas, which relies on recognized experts in the field, would be advisable. This effort should aim at not only gaining consensus but also revealing and exploring major differences in perspective.

IX.3.a.2. Validation

The validation of a complex model aims at demonstrating that the model bears a close resemblance to the system being modeled. The validation process is, in reality, three separate tasks: (1) technical validity; (2) operational validity; and (3) dynamic validity.

IX.3.a.2.1. Technical validity

Technical validity requires the identification of all model assumptions, including those dealing with data requirements and sources. It is especially important to document any divergences from perceived reality.

As a first step, one should identify all stated and implied assumptions, all decision variables, and any hypothesized relationships between variables. This step attempts to shed light on the correspondence between the model and the real world phenomena it attempts to explain. Three types of assumptions may be readily defined. First, the mathematical assumptions implicit in any large model include its functional form and the continuity of its relationships. A second type, content assumptions, define all model terms and variables. They should also define the scope and limitations of the model. The final type, causal assumptions, are concerned with the assumed or hypothesized relationships between terms and variables. Since these assumptions define the direction of flow in a model, they are capable of producing significant divergences from the real world phenomena.

Ideally, one would like to build a model which would produce true conclusions (predictions) whenever all of the assumptions were true. This property is known as modus ponens among logicians. Since most assumptions have their roots in a empirical argument, statements enter in a probabilistic rather than an absolute sense. Unfortunately, the strength of modus ponens does not apply to probabilistic statements, so that some other criteria must be used to reveal whether or not a model has a logical flaw. At one level, the axioms of Aristotle can be used to critique a model (e.g., the model contains one or more circular arguments). At a second level, logical formalism can be used to assess the adequacy of the translation of the model form into a numerical process that produces solutions. This involves:

1) determining if the mathematical or numerical calculations are correct and accurate;
2) analyzing if the logical flow of data and intermediate results are correct and consistent with our causal assumptions; and
3) ensuring that variables and relationships have not been omitted.

A concept which may be called the "principle of model economy" focuses on data validity. For example, an elegant model based on poor quality data may be of considerably less use than a simple model with slightly better quality data. In many cases, models use both raw data and transformed data in producing solutions. Since raw data are the basis for transformed data, their validity is essential. Basically the problem is one of assessing if the raw data are true in terms of accuracy, impartiality, and representativeness. If any of these characteristics are violated and the nature of the violation can be isolated and bounded, then a transformation may produce the desired data set. Data transformations can also have a significant impact on the validity of data. For example, aggregating time series data can force a system which is, in reality, recursive to become simultaneous. Similarly, the pooling of cross-sectional data may be inappropriate if two or more distinct populations are involved.

Assessing the predictive performance of complex models is the subject of a rapidly growing literature. The techniques used range from simple graphical analysis to the use of information theory. All techniques, whether highly qualitative or quantitative, seek to analyze the relationship between actual outcomes and predicted outcomes generated by the model. Predicted outcomes are of two kinds:

1) the values of the parameters used in the internal computational process of the model, and
2) the values of decision variables.

On the first level, one would review the statistical or related techniques used to obtain estimates for the relevant parameters. The main thrust here would be to demonstrate that the deviation of the estimated parameter value is as small as possible. The second level of analysis is more complicated, because it attempts to both document any divergences of actual and predicted values and identify what portions of the model appear to have caused them. These error decomposition techniques are especially difficult in models with a large number of interrelated equations.

IX.3.a.2.2. Operational validity

Operational validity attempts to assess the importance of any errors or divergences encountered when the model's technical validity is reviewed. Operational validity is concerned with whether or not the model can produce bad answers for proper ranges of parameter values, i.e., the model should be robust in that a user would find it difficult to make the model yield (in terms of the decision maker) an ostensibly wrong answer.

Sensitivity analysis is related to, but distinct from, robustness. This technique seeks to systematically vary the values of the model parameters to determine how much (i.e., how sensitive) the solution changes. The literature on sensitivity analysis has rapidly grown as more and more decision makers wish to know the answers to "what if" questions. The techniques for performing sensitivity analyses ranges from "brute force" Monte Carlo experiments to highly structured parametric programming.

The last aspect of operational validity and the most difficult is implementation validity. Implementation validity is concerned with the extent to which the real world system being modeled will respond in a manner indicated by the recommended solution. This task is difficult because if a decision maker knew how the system would respond to a given change in a parameter or decision variable, there would be considerably less need for a model. Consequently, even after the model is built and shown to predict historical occurrences well, it may not produce a good or even useful prediction of some future event. One possibility is that under some conditions the system does not appear to respond as the model predicts, whereas under others, it does. If one could determine under what conditions the system does not respond as predicted by the model, then some of the techniques used in assessing the accuracy of predictions could be used to attempt to isolate the cause.

IX.3.a.2.3. Dynamic validity

Dynamic validity is concerned with determining how the model will be maintained during its life cycle so it will continue to be an acceptable representation of the real system. The two aspects associated with dynamic validity are updating and review.

In updating, the evaluator needs to be satisfied that the model developers have established a procedure by which information is collected and analyzed to determine if and when model parameters or model structure need to be changed. It is also important that a process exists by which such changes can be incorporated into the model and disseminated to users.

A regular schedule for reviewing the success or failure of the model during its life cycle is also necessary. These reviews should be carried out regularly and should focus on documenting any systematic divergences between the solution predicted and the actual outcomes. The implications and means of accomplishing any proposed model changes should also be commented on. Periodically an extensive review should be conducted which produces a new evaluation of model validity that yields either a formal pronouncement that the model is still valid or that it should be substantially reworked or scrapped.

IX.3.a.3. Documentation

From a model user's point of view, documentation (the written description of the model) is essential if the model is to be usable, useful, and used. Since the abstract model is a mathematical representation whereas the operational model frequently appears as a computer code, it is necessary to verify that there exists a unique relationship between the abstract (mathematical) model and the operational model. It is important to point out that a third party assessment should be sufficient to verify this relationship. This would spare each user from carrying out the in-depth analysis that this task requires. An issue which each model builder should address is whether or not the computer code which describes a complex model is machine independent. Portability requires not only that the program can be run on a variety of machines, but that it produces the intended result. This step again should be a part of a third party assessment, although the provision of test cases which could be run and compared to a known solution would facilitate a move from one system to another. The final point in the evaluation of documentation is user friendliness. Complex models often involve subtle techniques which, in the absence of a buffer between the user and the model could cause frustration and lead to a highly inefficient use of the model. Documentation and an executive code should serve to shield the user from unnecessary detail without withholding any information which is essential to confidently use the model. One way in which the model developers can test their model is, again, through the use of a third party assessment. A second, and for this case perhaps more useful exercise, is to rely on a group of "casual users." These people might be expected to have some familiarity with the problem under study but would be less likely to analyze the model as deeply as its developers or a third party assessment team. Casual users are thus likely to represent better the intended user than a team of model builders or assessors.

There are no hard and fast rules for evaluating complex models because, to a certain extent, the type of model and its intended use will govern how much time and effort should be expended in carrying out the assessment.

IX.4. Two Computer Models for Assessing the Economics of Resource Recovery

Choosing among alternative solid waste management plans is a difficult problem requiring a careful accounting of all project-related costs. Computer models provide a convenient method for both organizing a decision maker's thoughts and for keeping track of all costs and their likely effects on different segments of the population. To adequately capture the realities of the situation, however, such computer models must be able to address the problem not only from the perspective of a typical community but also from that of a region representing a collection of communities. Although it is possible to develop a hybrid model which incorporates both perspectives, the differing objectives of decision makers and the data needed to assess their economic consequences justify the development of two complementary models.

The first efforts focused on the development of a community-oriented model with special emphasis on the economic tradeoff between selling newsprint for its fiber content versus incineration for its BTU value. This model was an extension of the results of the BIE wastepaper survey and the findings of NBS/ORM concerning this tradeoff (see Publications List 91 and 93). The model was developed by the Bureau of Industrial Economics at the Department of Commerce and is here after referred to as the BIE model. The second model focuses on the identification of a preferred regional plan for solid waste management. The Resource Recovery Planning (RRPLAN) model identifies the best combination of sites and sizes for all solid waste management facilities as well as the most cost-effective allocation of wastes to and among these processing facilities. The model also gives explicit instructions regarding which materials or forms of energy can be recovered from the waste stream and their allocation among competing markets. RRPLAN was developed by Edward B. Berman Associates, Inc.; a number of improvements were incorporated by the Operations Research Division at the National Bureau of Standards.

Perhaps the greatest difference between the two models is one of perspective. Whereas RRPLAN seeks to identify an optimal plan for solid waste management, the BIE model compares the costs of a fixed set of five waste management options. This distinction is necessary when sensitivity analyses are to be performed. Although both models can efficiently access the impacts of changing assumptions, the interpretation of the results may require greater qualification if the BIE model is used. This is due to the fact that sensitivity analysis in the RRPLAN model is based on perturbations about a solution which is preferred to a very large number of alternatives. Thus by fixing the set of waste management options at five, the BIE model user may not be able to see how the "structure" of the problem changes when one or more of the assumptions changes.

The degree of regional detail is another important difference. For example, if the case under study is for a single community then the BIE model should be used to determine if resource recovery is cost effective. Similarly, if several communities were to be studied in isolation then one should opt for the BIE model. If the case under study involves several communities, each of which must contribute to the construction and operation of a resource recovery facility, then the more complex RRPLAN model should be used. Similarly, if a potential for economies of scale in the construction and operation of solid waste management facilities exists, then the RRPLAN model should be used. This recommendation may be better understood when one recognizes that each community may be able to reduce its processing costs through centralization. An analysis of a single community would not be able to capture the effects that the processing of other communities wastes would have on its own costs. Finally, it is worth noting that both models can be used to assess a no resource recovery option.

A third major difference between the models has to do with the size of the model itself. Whereas the BIE model is quite small and could conceivably be executed on a programmable calculator, the RRPLAN model requires access to a computer system which satisfies certain software standards for the FORTRAN programming language. If access to a computer system is a problem or the intended user has a very limited computing budget, then the BIE model will have to suffice. Both models have documentation reports which give explicit guidelines for exercising them. The manual for the BIE model is entitled _An Economic Analysis of Resource Recovery Facilities and Waste Newspaper Recycling_ and is included as Appendix XI. Since the RRPLAN model requires more effort to set up and execute, it was necessary to prepare both a general purpose User's Manual and a Programmer's Manual describing how to set up and test the model on a particular computing system. (See Publications List 96 and 98.) The RRPLAN model is readily available to users on either magnetic tape or punched cards. The BIE model is available only as a listing within its documentation report (Appendix XI).

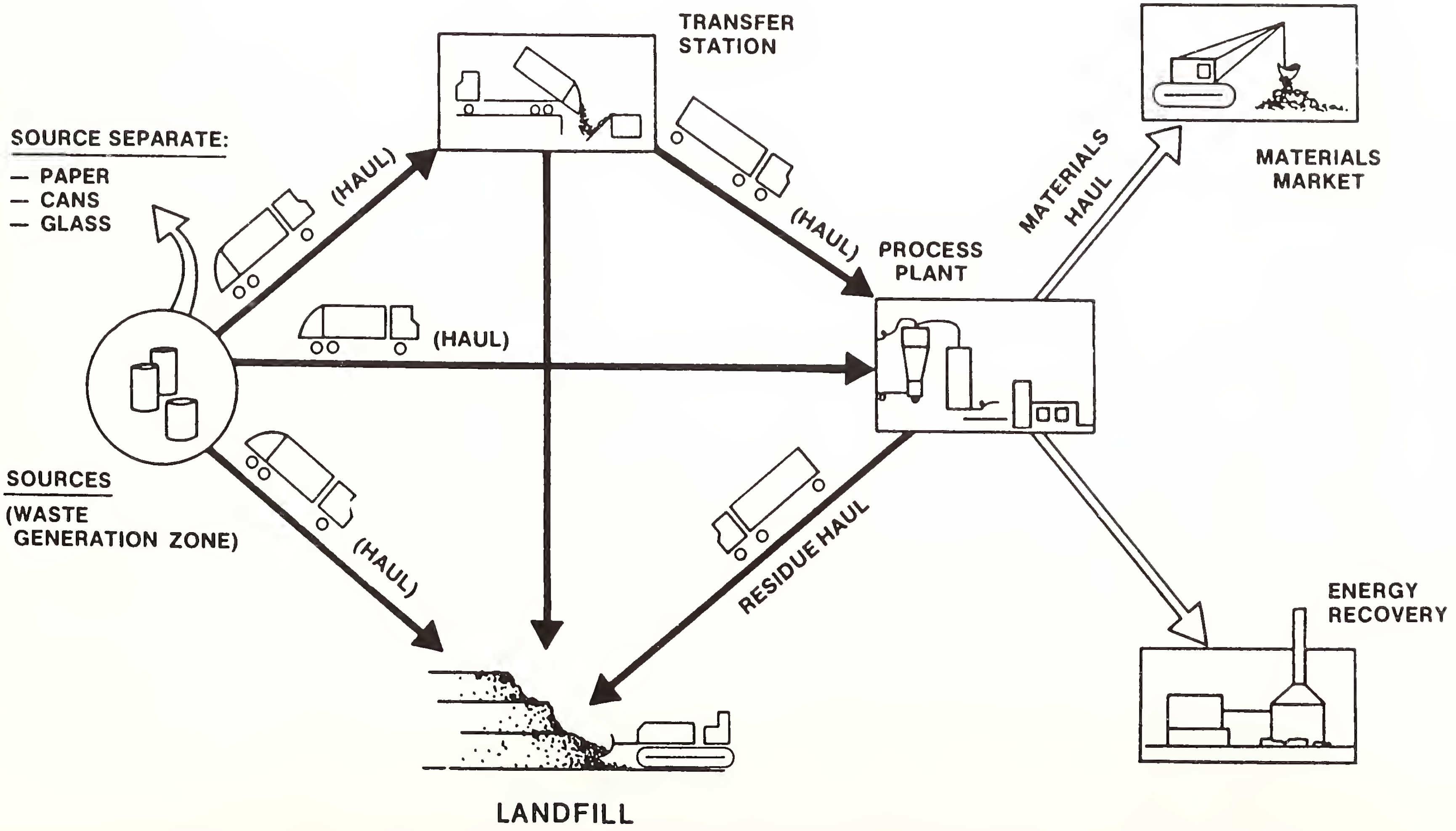
IX.5. The Resource Recovery Planning Model: A New Decision Tool for Solid Waste Management

The problem of identifying cost-effective methods for processing a region's solid waste stream goes beyond the identification of sites which are politically feasible. As fiscal pressures on communities increase, the economics of waste disposal becomes an ever more important issue. Resource recovery is thus an attractive alternative, providing planners with the potential for reducing the costs of processing the region's waste stream while conserving valuable land, material and energy resources. The economics of resource recovery are significantly more complicated than other approaches however, requiring an in-depth analysis of facility design and cost as well as market size, structure and location.

The Resource Recovery Planning (RRPLAN) model was especially designed to address the complicating factors mentioned above. On the one hand, RRPLAN explicitly incorporates potential economies of scale in the construction and operation of a solid waste processing facility. The model is thus able to support the basic tradeoff of savings from centralized processing versus the costs of additional haul required to bring it about. On the other hand, RRPLAN uses a detailed cost accounting system to attack the economic issues, carefully measuring the effects on overall program costs due to decisions affecting siting, routing, marketing, and financing. By integrating the technical issues of processing with these four major decision points, RRPLAN permits a wide variety of questions to be examined carefully.

The model consists of a set of equations relating sources of solid wastes, sites where the wastes can be processed and markets for energy or materials recovery. The model begins with a source of solid waste (e.g., a community in a region or a district in a metropolitan area). Each source has associated with it a location, an estimated waste generation figure, a series of options for preseparating paper, glass and cans, and a set of transportation linkages to sites where the waste is processed. Sites, as used in RRPLAN, may represent a landfill, a transfer station, an incinerator without heat recovery, or a resource recovery facility. Each site has associated with it a location, the type of wastes it can process, the operating and capital costs required to process the wastes, capacity considerations, outputs of wastes and marketable items and transportation linkages. The model can handle markets with downward sloping demand curves, constraints on capacity, and ones which can receive unlimited quantities of recoverables. Each market has associated with it a location a revenue schedule and transportation linkages (See fig. IX.1). Appendix XII provides a more detailed description of RRPLAN as well as a definition of terms. See Publications Lists 96 and 98 for full details. The model approaches the problem of siting and sizing solid waste processing facilities by approximating non-linearities in the capital and operating cost functions with up to three linear segments. Each segment has an intercept, a fixed charge, and a slope, an incremental cost associated with increased processing activities. The introduction of fixed charges causes the solution domain to take on a lumpy appearance. Unfortunately, this requires a specially designed optimization technique to generate meaningful solutions. The technique used in RRPLAN involves a fixed-charge linear programming algorithm with a forcing procedure to insure that the model can pass over an area of temporarily increasing cost in the solution domain to find the true optimum. The RRPLAN method of forcing represents a significant improvement over methods used in other models because each site which was in the solution is forced out of the solution and vice versa. This approach permits the solution domain to be searched in a more coordinated way by operating on all activities (e.g., transportation, processing, marketing) associated with a particular site. RRPLAN was originally developed by Edward B. Berman Associates, Inc. The Operations Research Division at the National Bureau of Standards incorporated numerous enhancements which should make the model easier to use.

HOW RRPLAN ADDRESSES THE ECONOMICS OF RESOURCE RECOVERY



TRANSFER STATION
SOURCE SEPARATE:
— PAPER
— CANS
— GLASS
(HAUL)
(HAUL)
(HAUL)
(HAUL)
PROCESS PLANT
MATERIALS HAUL
MATERIALS MARKET
SOURCES
(WASTE GENERATION ZONE)
RESIDUE HAUL
ENERGY RECOVERY
LANDFILL

Figure IX.1.

RRPLAN has been tested extensively through application to data from up-state New York, central Mississippi and New York City. Members of the NBS team met with representatives of each region studied to discuss the implications that the use of the model would have on project planning and implementation. The clarity with which the implications of various assumptions could be measured stimulated numerous discussions, indicating that the model may be used extensively by solid waste management officials. A series of mini-tutorials on the model were presented to officials from Mississippi, New York and California. A two-day workshop for a broad cross-section of solid waste management officials was presented at NBS in September, 1982. The workshop was sponsored by NBS, the Association of State and Territorial Solid Waste Management Officials, the Government Refuse Collection and Disposal Association, Inc., and the U.S. Conference of Mayors.

A complete set of documentation for the enhanced version of the RRPLAN model was developed by the Operations Research Division at NBS. The documentation consists of two reports. The first is a User's Manual which describes the input data requirements, the logic and data flow of the model, its major assumptions and limitations, and guidelines for interpreting the output. Step-by-step instructions on how to set up a test case as well as techniques for controlling the structure of the solution and for handling large or unusually complex cases are included in the report (See Publications List 98). The second report is a Programmer's Manual. It includes a functional description of the model which should facilitate the task of setting up the model on a different computer system. A series of tests are outlined which will permit programmers to verify if the model produces correct solutions (Publications List 96).

IX.5.a. Examples of the Use of RRPLAN

IX.5.a.1. New York City

The municipal solid waste problem facing New York City involves the interacting aspects of landfilling versus resource recovery. Landfilling has been the basic reliance for disposing of most of the City's refuse, but dwindling available space makes this a very short-term solution. In the past, incineration was utilized to prolong landfill space, but the increasing costs of non-energy recovering incineration, as pollution control requirements become more stringent, eliminated this method from consideration. City officials realized that new refuse processing plants which incorporate energy and material recovery to help offset capital and operating costs would be required to avoid the waste of former times.

Rising energy costs also threaten the economic viability of New York City and the quality of life of its residents. The city is 62 percent more dependent on oil for its energy supply than the rest of the Nation, and therefore is disproportionately vulnerable to the problems associated with the Country's reliance on oil. New York City energy consumers now pay over twice the national average for electricity.

Over the next fifteen years, the City of New York plans to build seven to ten waste-to-energy facilities throughout the five boroughs and to convert existing incinerators to resource recovery plants. These energy and materials recovery systems will significantly reduce the volume of solid waste that will have to be disposed of in the City's remaining landfills, while at the same time producing usable energy.

In support of this effort, the National Bureau of Standards has provided technical assistance to New York City in determining the economic and technical feasibility of resource recovery strategies in the application of the Resource Recovery Planning (RRPLAN) model. The Technical Advisory Center, Office of Recycled Materials, worked closely with the New York City Department of Sanitation (Office of the Deputy Commissioner for Resource Recovery and Waste Disposal Planning) and the New York City Energy Office in the collection of input data addressed to defining the essential characteristics of the municipal solid waste stream, transportation, waste disposal and processing sites, markets, and economic data. The goal was to utilize these data to assist the City generate a preferred plan for disposal of municipal waste among planned or existing processing facilities.

The numerical results which will be summarized here must be considered as only a rough first approximation to achieving this goal. Development of a valid "preferred plan" depends upon considerable amplification and refinement of the input data. Nevertheless, these first results certainly provide an indication of the general nature of a feasible plan. Thus, the RRPLAN model was capable of dealing with the data supplied in order to derive the basis for a least cost means to deal with the problem of residential waste in New York City.

The modelling support effort required to analyze the New York City data was shared between ORM, the Center for Applied Mathematics at NBS, and Dr. Edward B. Berman, Edward B. Berman Associates, who was under contract to NBS. The data received from New York City, when put into a form readable by the RRPLAN model, exceeded the capacity limitations of the optimization algorithm. The optimization algorithm used in RRPLAN consists of certain subroutines from the Waste Resource Allocation Program (WRAP). This algorithm is currently limited to 90 constraints (rows) and 360 activities (columns). Since each source and each site which is capacitated requires at least one row, it was decided to view New York City as having two parts. The first part consisted of Brooklyn and Queens, and contained 32 major sanitation department districts and 15 sites where municipal solid waste was processed. The second part consisted of the Bronx, Manhattan, and Staten Island. It contained 27 districts and 16 sites.

In performing the two sets of computer runs, a number of questions arose. First, the use of marine transfer stations required an analysis of both the barge hauling capability of each marine transfer station and whether or not a particular site could be barge-fed. This was especially important for the Brooklyn Navy Yard site where process steam was piped into the Con-Edison network. Second, since all of the marine transfer stations were not linked to the Arthur Kill site on Staten Island where ultimate disposal could be accomplished, it was necessary to set parametric limits on certain components of the marine transfer station's cost function. This parametric analysis served two purposes. First, it prevented certain capacity limitations in one part of the study from being exceeded by shipments indicated in the other part. The parametric analysis thus provided an overlay through which some degree of interdependence among the two parts of the study could be captured. Second, it permitted a limited analysis of how real flows (i.e., quantities processed) were affected by nominal values (i.e., process costs). This analytical capability was especially useful in performing the aggregation of sources necessary for simultaneously analyzing the entire city. The basic steps in the aggregation were as follows:

1) Districts which were always linked to the same site were combined and "locked" into that site;

2) Districts which were not locked into a site were only linked up to those sites which appeared to be efficient;

3) Sites which were not utilized were dropped from consideration; and,

4) The scale of processing activity was limited to what were perceived to be efficient levels.

The aggregated run consisted of 31 waste sources and 17 sites for processing. (One site and its associated waste sources were eliminated from the study at Dr. Berman's request.) Of the 17 sites, all but five were transshipment points. The five resource recovery facilities consisted of two water-wall incinerators for direct production of electricity, two water-wall incinerators for steam generation, and a refuse-derived fuel plant. The site which was omitted from the study was a water-wall incinerator for direct production of electricity. (It is included in the discussion which follows, however.)

The results of the run may be broken into two parts. The first part shows all direct shipments from the waste sources to a marine transfer station or to one of the six processing facilities. Results in table 1 suggest that over 30 percent of all wastes are first to be sent to a marine transfer station from which they need to be sent via barge to another facility for ultimate disposal. (Dr. Berman did not feel it necessary to handle process residue in the run since it would occupy only a relatively small volume of landfill space.) All wastes received at the marine transfer stations can be sent to either the Arthur Kill processor on Staten Island or to the Brooklyn Navy Yard. Table 2 shows that once these shipments are taken into account a significantly different picture emerges. Of the approximately 880 kilotons per year of wastes going to the marine transfer stations, about 750 goes to the Arthur Kill processor; the remaining 130 goes to the Brooklyn Navy Yard. Thus Arthur Kill's portion of the total waste stream rises from 6.3 percent to 32.1 percent whereas the Brooklyn Navy Yard's only rises from 10.6 percent to 15.1 percent.

Table IX.1. Process Activity Levels: Direct Shipments Only.

Facility	MSW Processed[a] (in kilotons per year)	Percent of Total
Arthur Kill	182	6.3
South Shore	930	32.1
West 215th Street	248	8.6
Canal Street	93	3.3
Brooklyn Navy Yard	309	10.6
Barretto Point	254	8.8
Marine Transfer Stations	878	30.3

[a] As reported by computer printout.

Perhaps the most significant point which can be observed from the results of the study is the model's preference for direct production of electricity. The three sites which generate electricity all are operating at 100 percent of their rated capacity (see table 2). All other sites where resource recovery takes place are operating at less than 50 percent of their rated capacity.

Table IX.2. Process Activity Levels: After Transshipment

Facility and Type	MSW Processed[a]	Percent of Rated Capacity[a]	Percent of Total
Arthur Kill (Electricity)	930	100.0	32.1
South Shore (Electricity)	930	100.0	32.1
West 215th Street (Elec.)	248	100.0	8.6
Canal Street (Steam)	93	20.0	3.3
Brooklyn Navy Yard (Steam)	437	47.0	15.1
Barretto Point (RDF)	254	41.1	8.8

[a] As reported by computer printout.

There are several problem areas which might reduce the usefulness of the results produced by RRPLAN, all of which stem from difficulties in obtaining the data necessary to exercise the model. First, the operating and capital costs figures used in the study were based primarily on data from the Louisiana case study. It is unclear whether these figures are appropriate for the New York City area. Second, the estimates for revenues from the sale of steam and electricity to Con-Edison were very soft. As a result, both recovery processes were assumed to generate the same revenue per unit of input. It would therefore have seemed advisable to perform a parametric analysis of the revenue function for each process. Finally, the study excluded at least one recovery facility which is currently under serious consideration.

IX.3.a.2. Central Mississippi

After the preliminary testing of the RRPLAN model with New York City, the model was applied to data from the Jackson area of central Mississippi. The object was to determine how RRPLAN could be used as the basis for developing the economic requirements for a variety of municipal solid waste options which might be exercised in the Jackson area.

Data on costs, markets, amount of MSW, inflation rates, and sites in the Jackson area were provided by the Bureau of Pollution Control of the Mississippi Department of Natural Resources. In summary, approximately 360,000 tons per year of MSW were calculated to be generated in the area. Steam and/or electricity from a potential waste-to-energy facility could be marketed--steam to the packing industry and electricity to the local utility. Source separation was not to be implemented regionally; there was little or no market for recovered materials except aluminum. Landfill could be used if necessary, i.e., siting could be accomplished. Financing for a waste-to-energy facility could probably be obtained at a 10 percent rate for a 15 year term; the facility lifetime was to be 20 years.

The first task for RRPLAN was to estimate the cost of an all landfill-no recovery option given collection costs, disposal costs, land costs and labor and transport costs in the Jackson area. This computation was meant to provide a datum against which all other options could be compared. RRPLAN computed the discounted cost of this option as $21.20 per ton for the 20 year period beginning January 1, 1985 and ending December 31, 2004. This cost can be interpreted to mean that it would take $21.20 of money at January 1, 1985 value to collect, transport, and dispose of one ton of Jackson area MSW and that all MSW for 20 years could be disposed at this discounted costs. All subsequent RRPLAN calculations were discounted on the same basis. Hence, in what follows, all costs are on the same basis, i.e., discounted to a value present as of January 1, 1985. A cost difference between two options of $1 per ton on this basis results in a $7.2 million cost difference for the total of 20 years since 20 years times 360,000 tons per year is 7.2 million tons of MSW.

RRPLAN was then instructed to "site" a waste-to-energy facility in the city of Jackson. In the absence of such a plant, eight landfills ranged around Jackson would continue to receive 360,000 tons per year of MSW at a discounted cost of $21.20 per ton. Once the new facility was in place, RRPLAN predicted that about 300,000 tons per year of waste could be processed there. Several landfills would cease operations; the remainder of the MSW would go to the rest. RRPLAN never predicted that siting, construction and use of transfer stations would be economically advantageous for Jackson. Note that RRPLAN selects the optimum activity level for each site, i.e., waste tonnage and most economical transport links to utilize these sites. For an input of 300,000 tons per year, facility capacity needs to be about 1150 tons per day.

Next, RRPLAN was instructed to arrive at solutions for the discounted cost per input ton as a function of steam and/or electricity revenues for various capital costs of the facility. Figures IX.2 and IX.3 show the results. Note that each ton of MSW was assumed to yield six MBTU of steam or 625 kwh of electricity delivered for use. (Assumes incinerator efficiency of 67 percent for steam conversion and turbine efficiency of 35.6 percent.)

If G_T is designated as the savings per ton of MSW handled as compared to the all landfill-no recovery datum, then

$$G_T = \$21.20 - D_C \qquad \text{(IX-1)}$$

where D_C is the discounted cost per ton in the case of the waste-to-energy plant. If G_T is positive, then the recovery option is more economical than landfill, if G_T is zero, the two are equal and if G_T is negative, landfill is more economical.

From figure IX.2 the value of D_C for steam, D_C^S sales can be deduced as:

$$D_C^S = \$\ 21.78 - 2.7\ S_{MBTU} + 1.07 \times 10^{-7}\ C_F \qquad \text{(IX-2)}$$

where S_{MBTU} is the sale price of steam per MBTU delivered at some temperature and pressure and C_F is the capital cost of the facility in dollars.

For break-even, i.e., $G_T = 0$, then:

$$S_{MBTU} = \$\ 4 \times 10^{-8}\ C_F + 0.216. \qquad \text{(IX-3)}$$

Figure IX.4 shows S_{MBTU} vs. C_F for this case. In general,

$$G_T = 2.7\ S_{MBTU} - 0.58 - 1.07 \times 10^{-7}\ C_F. \qquad \text{(IX-4)}$$

Similarly, from figure IX.3, the value of D_C for electricity, D_C^E, sales can be deduced as

$$D_C^E = 24.28 - 3.01\ E_P + 1.12 \times 10^{-7}\ C_F \qquad \text{(IX-5)}$$

where E_P is the electricity sale price (cents per kwh).

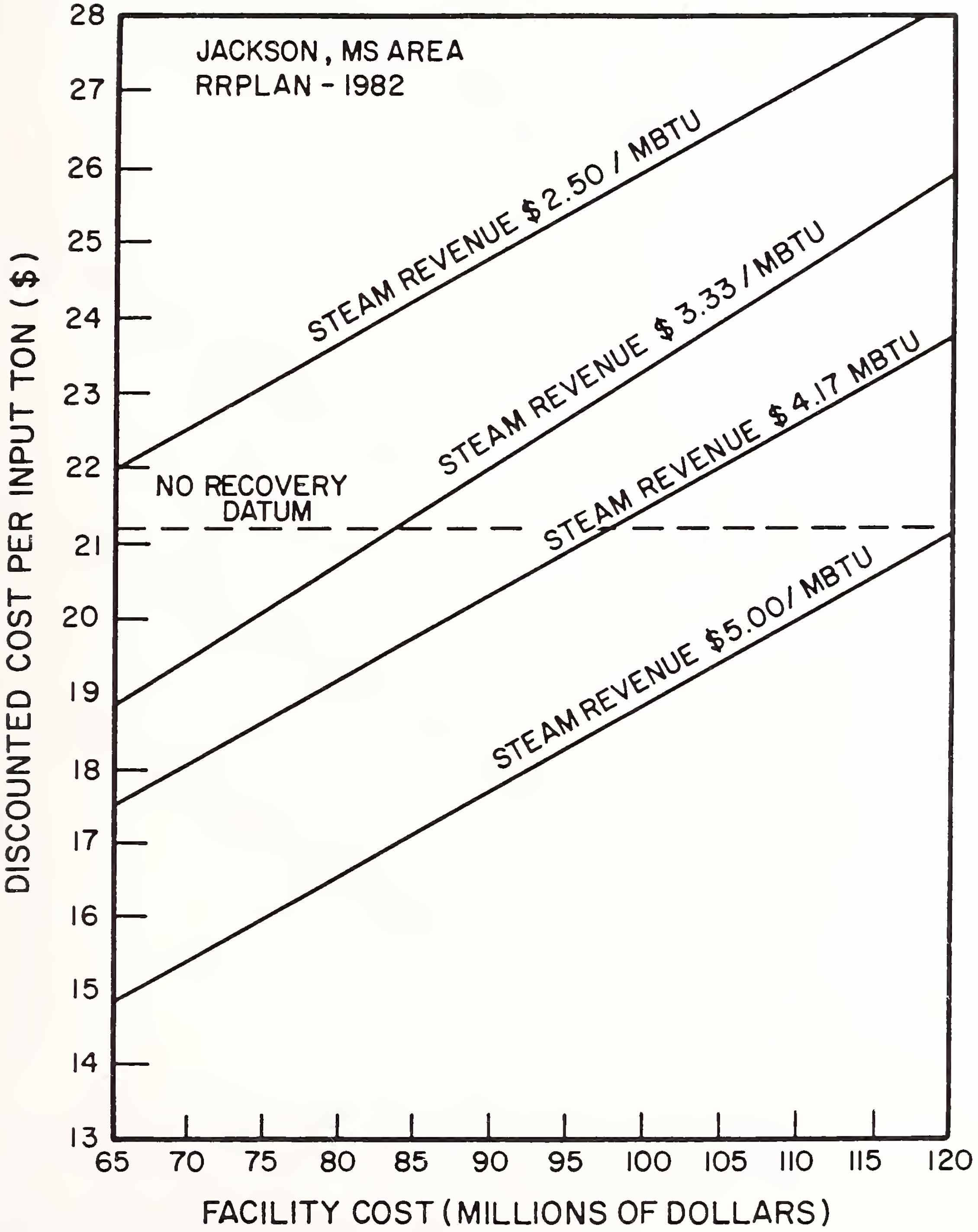


Figure IX.2. Relationship of steam revenues, facility cost and final discounted cost per input ton as compared to no recovery-all landfill datum.

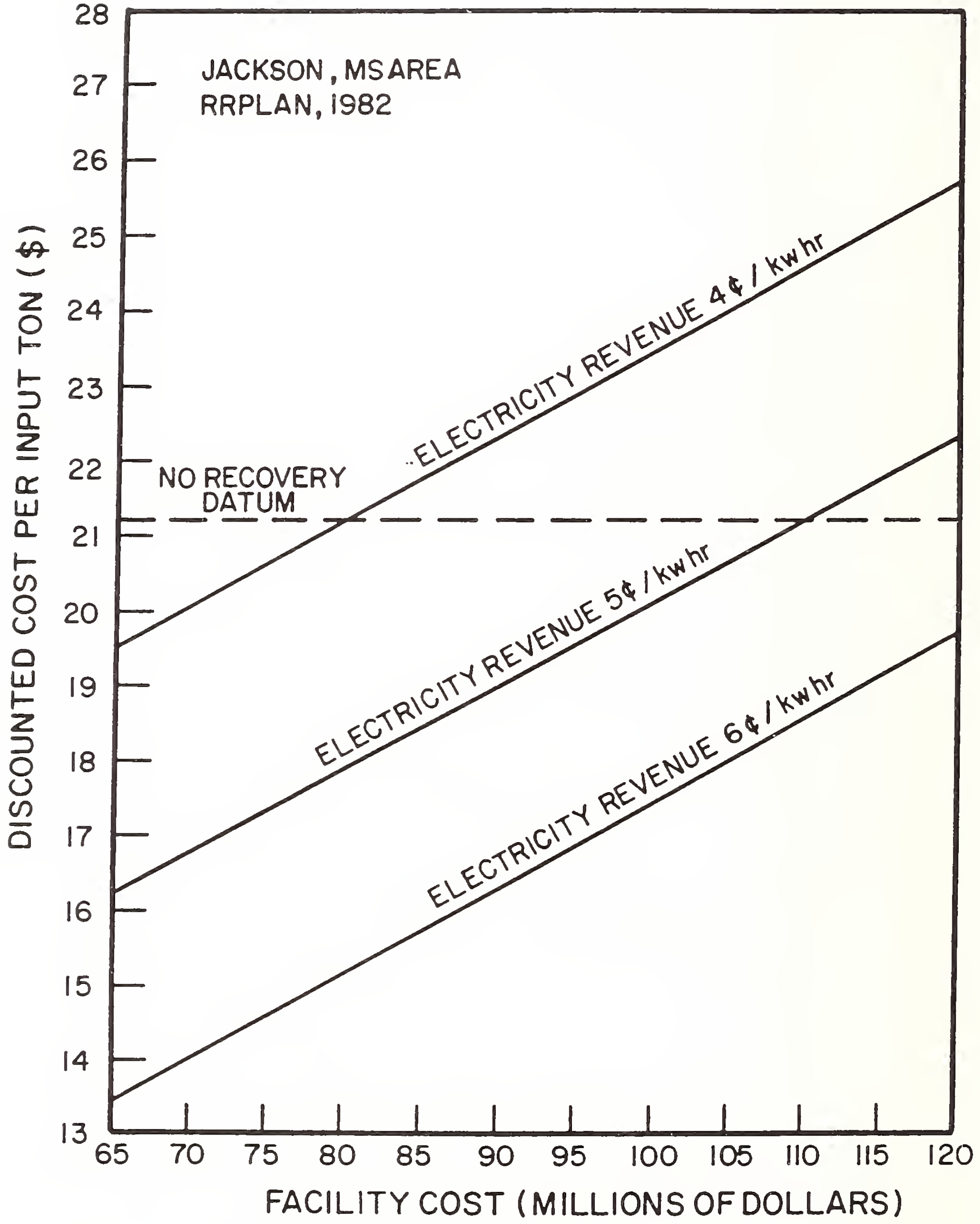


Figure IX.3. Relationship of electricity revenues, facility cost and final discounted cost per input ton as compared to no recovery-all landfill datum.

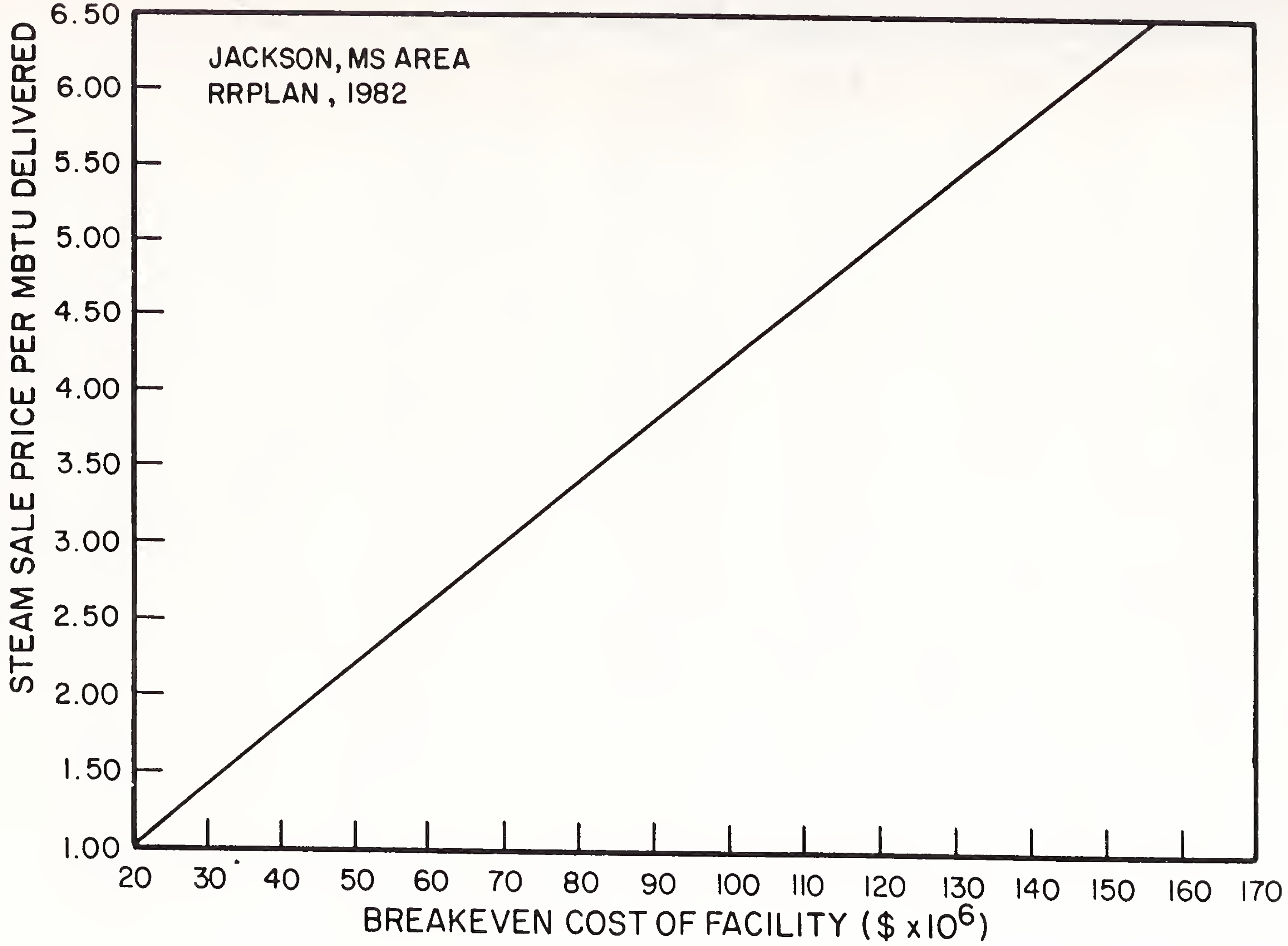


Figure IX.4. Relationship of steam revenue and cost of facility to "break-even", i.e., achieve a discounted cost per input ton equivalent to the no recovery-all landfill datum ($21.20).

For break-even, i.e., $G_T = 0$, then:

$$E_P = 1.02^3 + 3.70 \times 10^8 C_F \qquad \text{(IX-6)}$$

Figure IX.5 shows E_P vs. C_F for this case. Finally,

$$G_T = 3.01\, E_P - 3.08 - 1.12 \times 10^{-7}\, C_F. \qquad \text{(IX-7)}$$

In general, the return on investment, R_I, for the citizens if the Jackson area is:

$$20\, G_T\, T_Y / C_F = R_I \qquad \text{(IX-8)}$$

where T_Y is the number of tons of MSW actually converted to energy per year of operation.

Equation (IX.8) shows that if C_F is \$100 million and T_Y is 300,000, the R_I is 0.06 G_T or six percent per dollar saved over the lifetime of the facility. Thus, G_T needs to be in the neighborhood of \$3 to \$4 to fully justify the risk of investing \$100 million now in the recovery facility.

The cost of a facility to generate electricity is likely to be higher than that of a facility to generate steam. The turbine represents a considerable additional first cost. Thus, the value of $D_C^E - D_C^S$ is of interest in order to evaluate the additional initial risk:

$$D_C^E - D_C^S = 2.5 - 3.01\, E_P + 2.7\, S_{MBTU} + 1.1 \times 10^{-7}\, [C_F^E - C_F^S] \qquad \text{(IX-9)}$$

Equation (IX-9) enables one to calculate the affordable extra turbine costs for any value of $(D_C^E - D_C^S)$ which is deemed to make the risk acceptable. Figure IX.6 shows S_{MBTU} vs. E_P if this difference is set at

\$3.00, i.e., $D_C^E - D_C^S = -\$3$.

In general, if a firm value of E_P is available, then the sale price for steam to be equivalent is:

$$S_{MBTU} = 1.12\, E_P - 0.372\, [D_C^S - D_C^E] - 4.1 \times 10^{-8} [C_F^E - C_F^S] - 0.931 \qquad \text{(IX-10)}$$

On the other hand, if a firm price of S_{MBTU} is available, the trade-off for electricity is:

$$E_P = 0.892\, S_{MBTU} + 0.332 [D_C^S - D_C^E] + 3.65 \times 10^{-8}\, [C_F^E - C_F^S] + 0.831. \qquad \text{(IX-11)}$$

Thus, complete risk analysis for virtually any reasonable scenario can be performed in terms of market, price for steam or electricity and capital cost of the recovery facility. Note that all of these calculations assume that about 300,000 tons per year will actually

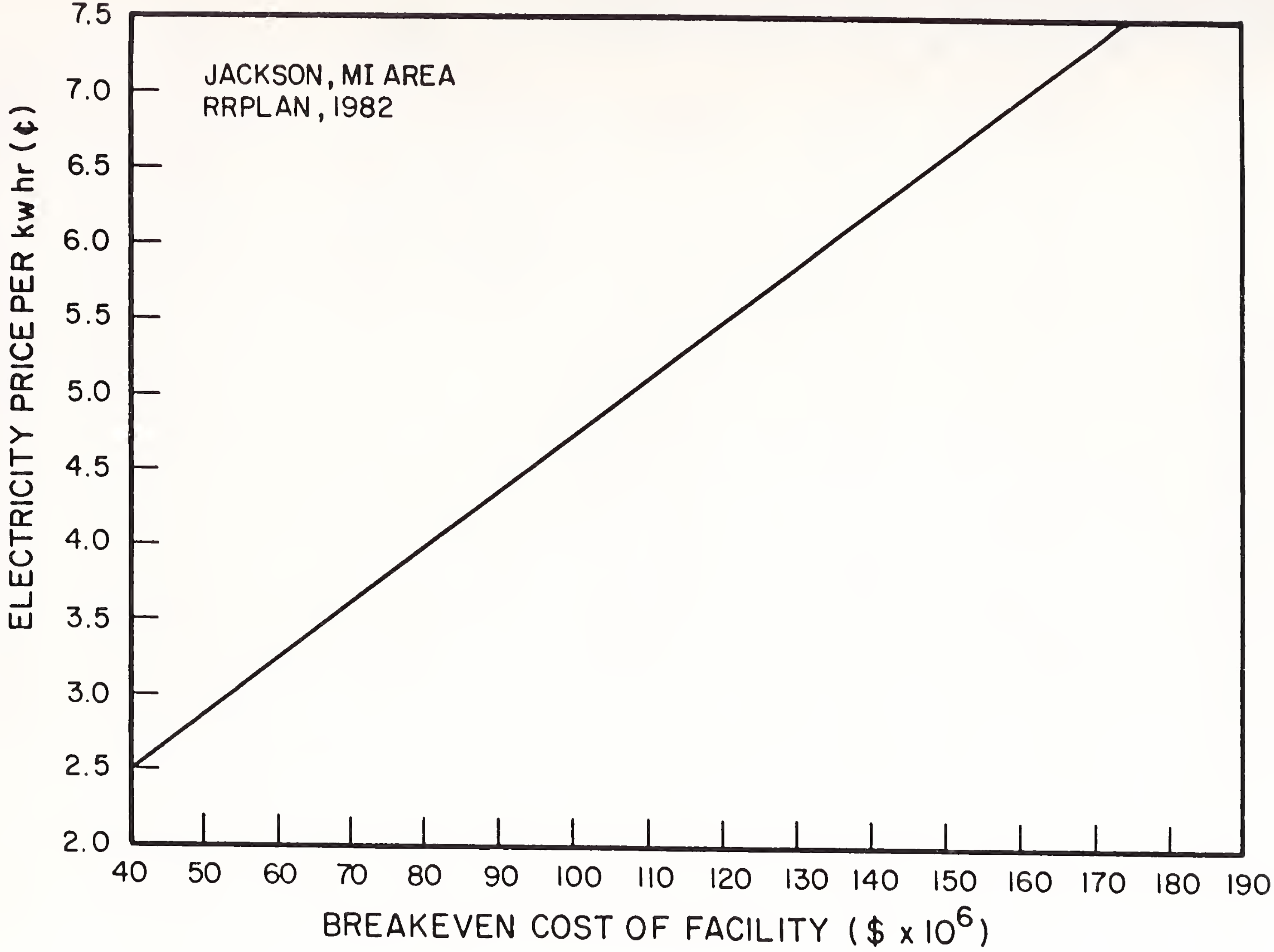


Figure IX.5. Relationship of electricity revenue and cost of facility to "break-even", i.e., achieve a discounted cost per input ton equivalent to the no recovery-all landfill datum ($21.20).

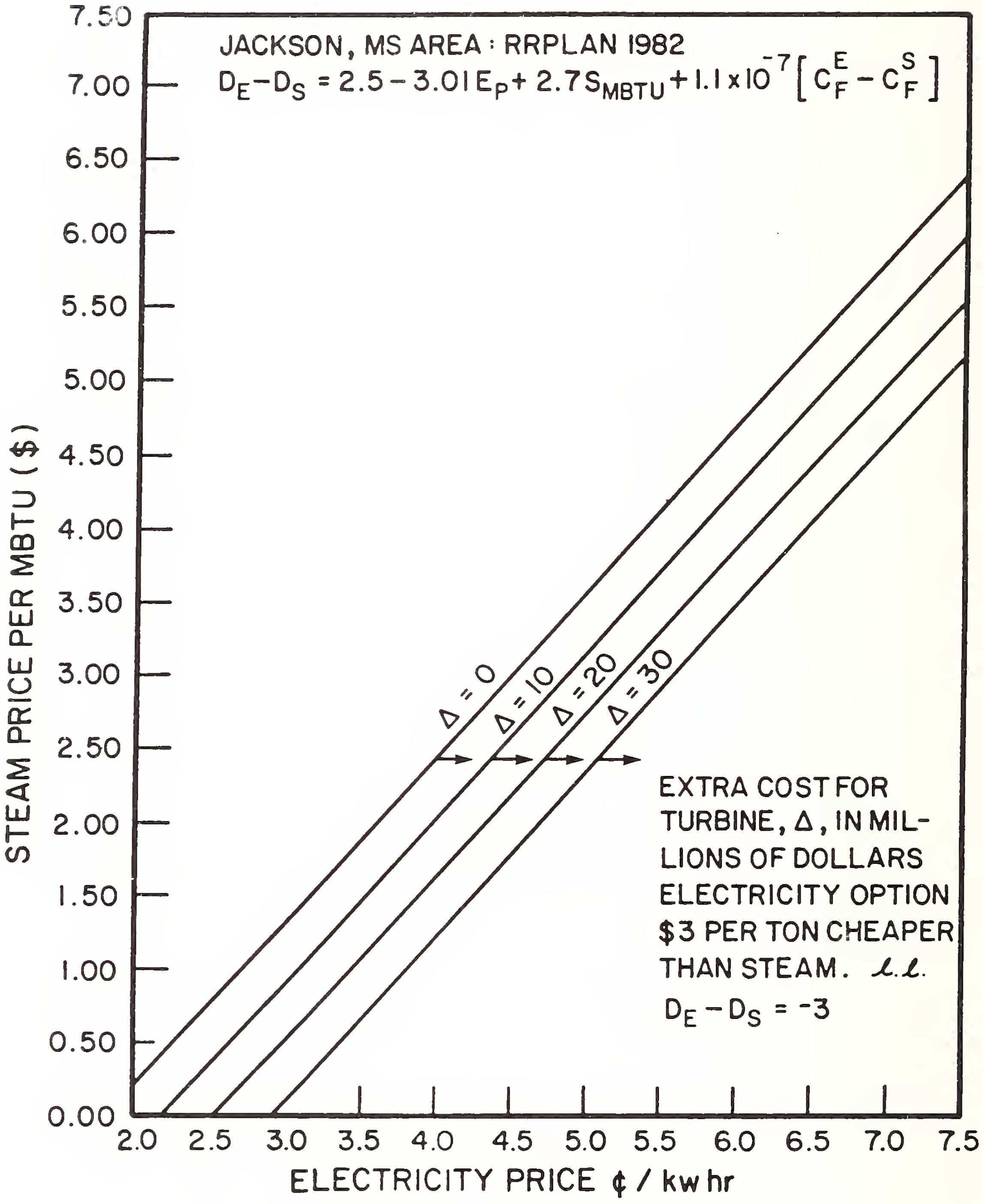


Figure IX.6. Risk of higher capital cost (for the turbine) to generate electricity for turbine, costs ranging from zero to $30 million: required electricity revenue as compared to steam to yield an (arbitrary) improvement of $3.00 per input ton for electricity sales.

be processed at the facility, and that all of the energy recovered from this MSW can and will be sold at some price. What remains is to consider the possibility that this value of T_Y will vary.

In order to compute the dependence of D_C on the number of tons peryear, T_Y, which must actually be processed, the general form of the relationship for D_C may be written as:

$$D_C = a(C_F/T_Y) + b + c\ R_T \tag{IX-12}$$

where R_T is the income or revenue for each input ton of MSW processed through the facility. Note that if a tipping fee is charged per input ton of MSW, its value is part (or all) of R_T. The coefficients a, b, and c depend on the discount rate, terms of loan, lifetime of the plant, transport costs and so on, i.e., all of the input data for RRPLAN.

The results presented for Jackson as Equations (IX-2) through (IX-11) can be used to deduce a set of normal (most statistically valid) equations in order to derive a, b, and c for this case:

$$D_C = 0.033\ \ (C_F/T_Y) + 21.20 - 0.407\ R_T \tag{IX-13}$$

Equations (IX-12) and (IX-13) are entirely analogous to the one suggested by Yakowitz (Publication List 78) for the approximate break-even cost for any resource recovery facility. The difference is that Equations (IX-12) and (IX-13) represents fully discounted dollars for the lifetime of this facility while the relation given by Yakowitz is in current dollars for the first year of a publically owned facility.

If only T_Y is allowed to vary in Eqn (IX-12) then differentiation yields:

$$\Delta D_C = (aC_F/T_Y)\ \ (-\Delta T_Y/T_Y) \tag{IX-14}$$

If C_F is \$100 million, and T_Y is 300,000, then

$$\Delta D_C = 11.0\ (-\Delta T_Y/T_Y). \tag{IX-15}$$

Each one percent that T_Y varies from 300,000 changes D_C by eleven cents. The minus sign means that a decrease in tonnage will raise D_C and vice-versa. Thus, if for some reason tonnage falls by about ten percent, D_C will increase by \$1.00. Therefore, in the Jackson case, the amount of waste available for processing and the efficiency of processing are crucial. Further details for the Jackson, MS case are in Publication List 112.

IX.6. General Assessment of RRPLAN

The relationship given in eq. (IX-12) is the general economic expression governing resource recovery or most other businesses where a product is produced via the use of capital equipment and sold on a per unit basis. For the case of resource recovery, one wishes to minimize the values of a, b, and c. In effect, the optimizer section of RRPLAN uses advanced techniques of operation research to select values for a, b, and c, given the input data supplied so as to minimize D_C. However, uncertainties in a, b, and c depend upon:

1) Formulation of the model mathematically.

2) The operations research algorithm used to optimize the mix of a, b, and c.

3) The data from which the numerical values of a, b and c are derived, e.g., discount rate, life of capital stock, inflation rate, market stability, labor costs, insurance costs, transport networks and costs, etc.

4) The statistical estimate of error in the normal equations used to obtain a, b and c as specific numerical results.

Differentiation of eq. (IX-12), assuming that all of the variables can have uncertainty and are independent of one another yields:

$$\Delta D_C = aC_F/T_Y(\Delta a/a + \Delta C_F/C_F - \Delta T_Y/T_Y) + b(\Delta b/b) + cR_T(\Delta c/c + \Delta R_T/R_T). \qquad \text{(IX-16)}$$

Items (1) through (4) on the foregoing list are responsible for the uncertainty terms for a, b, and c. The other uncertainty terms represent cost variations, e.g., overruns for the capital stock, variations in tonnage processed annually, and cost variations for the revenue per ton actually processed.

Equations (IX-12) and (IX-16) represent the economic and technical challenges facing planners and decision makers in selecting an optimum scenario for resource recovery. (If other factors, such as using the outputs of resource recovery to fuel other industries, enter, the process becomes even more complex.) In the case of resource recovery, RRPLAN, in effect, provides the best estimates for a, b, and c that are likely to be obtained from any given set of input data.

Nevertheless, a method to evaluate the functionality of a, b, and c with respect to variations in input data would be extremely useful. Then, local planners could be in a position to assess the effect of specific uncertainties on the economics of any resource recovery scenario. For example, in the case of the data for Jackson, if C_F = \$100 million, T_Y = 300,000, R_T = \$30, then eq. (IX-16) becomes:

$$\Delta D_C = 11\ (\Delta a/a + \Delta C_F/C_F - \Delta T_Y/T_Y) + 21.20(\Delta b/b) + 12.21(\Delta c/c + \Delta R_T/R_T). \qquad \text{(IX-17)}$$

Assuming that C_E, T_Y and R_T are known to within one percent, but that a, b, and c are known to within five percent, eq. (IX-17) yields a ΔD_C of \$2.56 while eq. (IX-12) yields a D_C of \$20.00, or a relative uncertainty of about 13 percent in D_C. Hence, for purposes of planning in Jackson, the uncertainty of the "real world" can perhaps, be guessed as about 20 percent. Still, if a combination of costs, tonnages and income can be obtained such that RRPLAN predicts a reduction in D_C of \$3.00 to \$4.00 with respect to the all landfill-no recovery case (which is also subject to similar uncertainty computations), then the risk may be associated with investing in the resource recovery facility is probably worth serious consideration.

The role of RRPLAN in assessing resource recovery options can be summarized as follows:

1) RRPLAN selects a minimum cost plan by comparing the various D_C values for each option.

2) In every case, the optimizer minimizes individual D_C values as a function of the specific input data offered by the user.

3) RRPLAN does not compute unique values for the variables a, b, and c in eq. (IX-12).

4) By varying the input data to RRPLAN, specific estimates for a, b, and c can be obtained as well as preliminary estimates for the uncertainties in these variables. RRPLAN probably provides the best available means to predict a, b, and c accurately.

5) Equation (IX-16) represents the "risk evaluator" for a specific set of data and the uncertainties in these data.

6) Until all terms in eq. (IX-12) and (IX-16) are evaluated numerically for various options, a planning basis for a waste management strategy is incomplete.

Thus, RRPLAN, if used properly, provides the foundation for planning. But considerable additional assessment may well be necessary in order to choose the proper strategy for a given region. This assessment involves probabalistic estimation for the input variables (discount rate, costs, etc.) followed by multiple RRPLAN evaluations. The results will provide values for all terms in eq. (IX-12) and (IX-16). Unless all of these steps are taken, RRPLAN results need to be treated with extreme caution.

RRPLAN, as developed for and by NBS/ORM, represents an appropriate means to begin evaluation of specific resource recovery options for a city, state, or region. The input data requirements will tend to require the prospective RRPLAN client to determine as accurately as possible each item of data. If these data are not properly obtained, the risks of adopting a resource recovery plan become much greater; the U.S. has had several cases where resource recovery options have not lived up to proponents expectations. Careful data assessment, RRPLAN and solutions to eq. (IX-12) and (IX-16) should help to reduce the risk associated with resource recovery. In turn, the data gathering process and the subsequent RRPLAN and probablistic analysis should clearly highlight potential or actual institutional problems. (See Appendix XVI for further details.)

RRPLAN can be applied to recovery of hazardous or non-hazardous industrial waste with some modifications. Thus, all waste classes which were dealt with by RCRA can be taken into account. The preceding general assessment is appropriate for all classes of waste.

IX.7. General Market-Related Activities of NBS/ORM

IX.7.a. Fate of Fiber

One general market area which NBS/ORM chose to consider directly concerned the burn, recycle or bury issue for wastepaper. Established wastepaper collectors, recyclers and dealers became concerned that waste-to-energy facilities might reduce supply of waste paper and/or bid up the price to a point where recycling was no longer economically feasible. NBS/ORM analyzed the situation and reported on the economics of several possible options for wastepaper (See Publications List 78 for details). In addition, both the BIE and RRPLAN models allow for detailed consideration of the optimum uses for waste paper in a given region.

NBS/ORM concluded that a universal solution for the "best" use for wastepaper does not exist. Nevertheless, for most situations, source separation of the newsprint fraction office paper including computer materials, and corrugated stock will not seriously harm the economics of a waste-to-energy facility. On the other hand, as shown in NBS/ORM Publication #78, certain situations could occur in which the waste-to-energy facility's requirements could adversely affect businesses engaged in recycling of wastepaper.

IX.7.b. Other Market Studies

Many other NBS/ORM activities, which have already been described, contributed directly to fulfilling the mandates of Section 5003(1) and 5003(2) of RCRA concerning markets. These include the procurement analysis with state agencies (Publications List 56), the bid modifier development (Publication List 74), the GLBC/Michigan results (Publication List 95), and the waste solvent based recovery of metal from steel making wastes (Publication List 115). The entire thrust of the recycled oil program was aimed at showing that such oil could be equivalent to virgin oils. Thus, used oil could gain general market acceptance. The U.S. Conference of Mayors developed, under a DOC grant, a critical issue report on energy markets for recovery from MSW.

In addition, NBS/ORM participation with the Waste Management Policy Group (WMPG) of the OECD, provided many useful insights into the market issues associated with recovered materials destined for waste. Other industrialized nations have been applying resource recovery methods longer than the U.S. Experience concerning waste-to-energy technology and economics, tire recycling, source-separation techniques and results, conditional effluent taxes and other waste management issues was shared within the WMPG. Several OECD publications, e.g., Waste Tyres, Source Separation, Energy from Municipal Waste are available or in press. NBS/ORM contributed to these efforts; the results provide a useful summary of economic and technical issues associated with recovery and marketing of materials destined for waste.

IX.8. Efforts to Encourage Development of New Uses for Recovered Materials (Section 5003(3) of RCRA)

An example of innovative technology which reduced barriers to the use of reclaimed newsprint was the development of a quick, economically and environmentally valid de-inking process for newspapers. This process is crucial to the reclamation of many thousands of tons of old newsprint for recycling as usable newsprint. While this de-inking process is a success story, many technical, institutional and economic barriers continue to exist with respect to new uses for recovered materials.

One case which NBS/ORM dealt with directly concerned problems associated with recycling of bi-metal beverage cans, i.e., cans with ferrous metal bodies and aluminum tops. These tops seriously degrade the processing of detinning ferrous cans to reclaim steel and pure tin by consuming the chemicals needed. Thus, the return on investment to the detinner may be inadequate, and a potential market for waste cans may be lost. NBS/ORM realized that if some form of existing or innovative technology--either providing an all steel can with easy to open yet safe top, or removing the existing difficulty in the detinning process--the potential market barrier might be reduced or even eliminated.

Developing new technology for can tops was clearly the purview of the private sector. Therefore, in cooperation with representatives of the ferrous scrap and detinning industry, NBS/ORM sponsored efforts to reduce the difficulties created by the presence of the aluminum tops in the detinning process.

Several tons of can scrap were subjected to special shredding and grinding operations. The object was to use the difference in hardness between the ferrous (hard) and aluminum (soft) to provide chips of the ferrous and almost an aluminum powder. This material could then be spread out and subjected to a magnetic separation. Thus, the two metals were separated into aluminum scrap and nearly aluminum free ferrous for the detinner. As a bonus, detinning efficiency was enhanced since the chips of ferrous offered higher surface area to the chemical bath. In times of strong demand for ferrous scrap, this process is economical. When the demand for ferrous scrap is weak, this process is economically marginal (See Publications List 117 for details).

Other major direct NBS/ORM efforts to encourage new uses for recovered materials include the GLBC/State of Michigan work, procurement efforts, work on ash and the solvent based recovery of metal from steel mill scale and sludge, all of which have been described previously.

IX.8.a. Technology Commercialization Program (MBDA)

Within the Department of Commerce, the Minority Business Development Administration (MBDA) developed a technology commercialization program meant to assist minority firms to enter and compete in the rapidly growing areas of the economy (industries), which are technology-based, and to enter these new industries at the earliest practicable stage so that they can compete as the industry grows rather than entering after the initial growth has taken place and the opportunities have been diminished.

The program has established the first nationwide network of resources, in both government and industry, specifically designed to provide the sophisticated level of services required for technology-based minority firm opportunities.

The MBDA program, with its government/industry partnership, has begun to define and attack those problems which inhibit technological growth as they relate to minority business.

From the beginning, the focus of program activity has been to coordinate government and industrial resources (i.e., create a public/private sector partnership) in support of minority enterprise.

The program operates on the following four assumptions:

- The process must be profit-oriented.
- It must be set primarily in the private sector with the government role one of continuing coordination and resources development.
- The system must utilize the normal business process of the participants to the greatest extent possible.
- The cost to the minority firm in determining product potential must be kept at the absolute minimum.

How it operates -- The program provides a much needed brokering function for the development of new products and services, providing a coordinated process for gaining access to and matching information regarding: available technologies with commercial potential: markets looking for new products; and sources of financing available for new product development--all to be matched with interested and qualified minority firms.

One of the program's principal functions is to provide, where possible, such direct services as evaluations of a new product regarding its technical soundness and potential market. This process helps to facilitate a match with an appropriate potential source of financing.

- The Technology Information System keeps program participants updated on the status of all of the projects that TCCs and the Sectoral Development Unit are developing, and is beginning to build a pool of information on technologies, markets, adaptive processes, source of financing, and the MBE by specialty.
- The Sectoral Development Unit, in its initial year of operation, will concentrate on identifying and ranking sectors of the economy with growth potential. This effort will be compatible with the commercialization process being carried out through the TCCs.

Who benefits?--The primary beneficiary is the minority firm who commercializes the technology and is provided with the opportunity to enter developing markets. Additionally, developers of technology, both in government and industry, sources of financing, markets seeking new products and services benefit by participation in the program.

What are the important features?--The brokering and evaluation functions described above and the public/private sector partnership which has resulted in a unique commercialization process, as opposed to the previously disaggregated approach to technology transfer of utilization, are the most important features of the program.

Number of beneficiaries--The generic process of technology commercialization is long term in nature. Recognizing this, we have specifically designed our program to be flexible in nature and to respond to the need of the individual project under development. It is not an assembly line process. We are providing assistance in areas which were formerly closed to minorities and in areas of the economy which offer the greatest opportunities for growth.

Types of businesses benefited--The program is designed to assist minority firms which are or have the capability of becoming second or third tier firms. This would include manufacturers, distributors, and retailers in growth areas of the economy.

One of the firms aided by this program developed a thermal method to recycle iron units from oily mill scale and sludges. The oil helped provide energy for the process. The iron units produced can be sent directly to the blast furnace. (This process was so successful that its inventor was named Small Business Man of the Year in 1981.) The innovative technology thus reclaims energy, reduces hazardous waste and provides iron for the blast furnace which otherwise would have been destined for waste.

Another firm has developed methods to recycle solvents and other useful substances from liquid hazardous waste. In addition, this firm's treatment technology also reduces the volume of such waste which must be disposed. A third effort dealt with zinc recovery from a smelter in New Mexico.

The Economic Development Administration (EDA) also supported efforts to develop new uses for recovered materials. Results relating to electric furnace dusts have already been discussed. In addition, a wood waste-to-alcohol facility in Maine received EDA aid. The experimental pyrolysis unit for converting waste-to-energy in the City of Baltimore also received partial support from EDA.

X. EVALUATION OF COMMERCIAL FEASIBILITY OF RESOURCE RECOVERY FACILITIES (SECTION 5004 OF RCRA)

X.1. Congressional Mandate

Section 5004 of RCRA (42 USC 6954) authorizes the Secretary of Commerce to evaluate the commercial feasibility of resource recovery facilities, to publish the results of this evaluation and to develop a database for purposes of assisting persons to select such a system. Department of Commerce Organization Order 10-1, Amendment 5 caused activities under Section 5004 to be placed under the purview of NBS/ORM in January 1980.

X.2. Specific Activities

Prior to 1980, the Office of Environmental Affairs (OEA) of DOC had initiated two important activities relating to Section 5004. (Note that OEA ceased operations in 1981.) These activities were:

1) Organization and sponsorship of an International Conference on Urban Industrial Development through Resource Recovery (Held April 17-18, 1980 in Detroit, MI); and

2) Development of a project whereby the U.S. Conference of Mayors (USCM) evaluated possibilities for urban-industrial development through resource recovery (this project was funded by EDA).

X.2.a. International Conference on Urban Development Through Resource Recovery

The Detroit Conference was meant to inform persons such as Mayors, county, and state officials as well as representatives of private enterprise and the general public of the DOC concept of resource recovery as an integrated industrial strategy to promote urban economic development. Topics covered included:

- o Economic impact of resource recovery and related industries

Effect on employment, the tax base, and other economic considerations, both directly and through the industries resource recovery attracts.

- o Policy concerns

What is holding up further economic development through resource recovery, and how can some institutional barriers be overcome?

- o Resource recovery industrial parks

Can this concept work in any but the largest of cities? What variations on this siting concept are viable? What has been tried thus far?

- Attracting industry

How resource recovery fits into an industrial development strategy, by attracting or keeping related user industries.

- Lessons from the Europeans

How various Western European communities solved some of the industrial barriers facing U.S. projects through government/industry cooperation.

Some 300 persons attended this Conference. A number of attendees contacted the NBS/ORM Technical Advisory Center after the Conference for specific follow-up assistance. Most of these requests concerned the need for technical and economic data to evaluate the commercial feasibility of various resource recovery options. The Technical Advisory Center provided these data along with a very brief analysis of the specific problem raised in the request. For example, a state prison official was provided data on small waste-to-energy units as well as a calculation method by which he could determine if such a unit could economically and reliably provide supplemental energy to the prison. Several dozen such requests were answered.

The Conference placed special emphasis on the feasibility of resource recovery options in terms of the broad range of questions and concerns facing city, county, and state administrators. In summary, the major concepts which the Conference dealt with included:

1) Resource recovery programs can be used as an urban economic development tool when the benefits derived from purchasing energy and materials from resource recovery are concentrated in urban commerce and industry, and where there are multiple opportunities for marketing the recovered energy and materials.

2) Energy produced through resource recovery facilities can be sold to specific industrial or commercial clients, targeting energy benefits to particular users. Additional economic development benefits can be derived by developing industries which utilize recovered resources. If fully developed, a total economic development/resource recovery effort could close the cycle of manufacturing, consumption, and disposal in a given geographic area.

3) Resource recovery can be viewed by economic development agencies and project developers as another tool to be added to their list of incentives which can attract or retain industries in their cities. This interaction between resource recovery and economic development activities may result in decreasing the overall costs while streamlining the development of resource recovery programs.

4) Approaching resource recovery from an economic development perspective may also provide additional opportunities to organize public and private sector interests so as to realize additional energy, economic, and environmental benefits from a resource recovery effort. (See Publication List #77.)

X.2.b. U.S. Conference of Mayors Grant

In order to evaluate the feasibility of applying these concepts in the real world, DOC acting through OEA and EDA provided a grant to the U.S. Conference of Mayors to perform this evaluation by means of a series of case studies of cities which had or were then developing resource recovery programs. The initial USCM survey found that:

- The majority of practices appear to be directed toward waste disposal rather than conservation objectives.
- Many of the planning processes used by communities to develop Resource Recovery Systems do not assure that the best technology available will be selected for that particular site.
- The process of Resource Recovery development requires the coordination of a variety of institutions and political entities. This in turn requires the development of local political expertise and local leadership that is notably missing in the current planning and implementation activities.
- The sciences most frequently considered in the area of Resource-Recovery-from-waste, do not systematically consider the alternatives beyond the energy recoverable; those being extracted materials and new raw materials for industrial use.
- In assessing the economics of Resource Recovery, communities do not appear to adequately take into account such economic benefits as job creation, conservation, overall community economic benefits, or the potential to obtain from a coordinated resource recovery effort benefits which can be secured for target populations within a community.
- The current methodology by which many communities currently approach the development of resource recovery options and programs is expensive, and often unproductive. This is a significant national problem in that it involves expenditures of considerable size for planning, feasibility study, and capital investment.
- The concept of Economic Development through Resource Recovery appears to be a concept around which many of these issues can be focused and resolved.

Specific case studies were carried out in order to:

- develop a database including the technical, financial, and political aspects of resource recovery, past and present;
- assess the role of the political leader and the various institutions (private and public) in the project dynamics;
- determine how local decisions regarding waste disposal have been made in the past - and what informational resources necessitate sound future decisions;
- examine the potential for the Urban Resource Recovery Industrial Park concept as an economic development tool;
- examine the acceptance of resource conservation - energy and materials recovery; and
- increase the awareness of the local officials regarding resource recovery as a potential economic development tool.

The issues addressed in the case study data gathering process were represented by the following general categories:

- Background of Project
  - Motivation
  - History (Key Actors, Key Events)
  - Alternatives Considered
  - Technology Employed (How was it procured?)
  - Markets Used (Energy & Materials)
  - Costs (Planning, Construction, Operating)
  - Financing Approach (Alternatives Considered)
  - Siting Approach
  - Decision-Making Process (Type of Government Structure)
  - Public Participation (Project Team)
  - Institutional Barriers Overcome (Especially Waste Stream)
  - Socio-Political Impacts
    - Support for Project (Constituency)
    - Political Debate? Liability or Asset?
    - Impact on Community (Pollution, Traffic, Image)

- Economic Development Issues
  - Benefits to Municipality of Resource Recovery Facility
    - Jobs
    - Ratables
    - Taxes
    - Host Community Fees
    - Improved City/County Relations
    - Energy & Materials Produced
    - Industries Supported (Markets)
    - Reduction in Environmental Costs (Landfills)
    - Reduction in Collection Turnaround/Maintenance
    - Reduction in Transportation Costs for Products Manufactured
  - Regional and National Benefits of Resource Recovery Facility
    - Reduced Landfill Volume Required & Number of Facilities
    - Energy Conserved
    - Energy Produced
    - Balance of Trade Improvement
    - Reduced Welfare Costs (Due to Unemployment)
    - Regional Reinvestment of Capital
    - Minority and Women Employment
    - Small Business Participation
    - Open Space Preserved
- Current Problems
  - Facility Operating Technically?
  - Facility Economically Viable?
  - Waste Stream Problems?

- Market Problems?

Eleven critical issues were identified:

1) Utility vs. industrial markets.

2) Development of new marketing strategies (including the desire for multiplicity of these markets).

3) Public vs. private cooperation in project development.

4) Priorities and goals among state and federal energy, environmental, and economic development agencies and their interrelationship or lack of it.

5) Recycling as an economic development tool/what industry can do to reuse/recover its own waste(s).

6) Life cycle costing with consideration of problems due to duration of time for project implementation.

7) Financing/tax incentives.

8) Large scale vs. small scale regionalization.

9) Role of the consultant.

10) A champion with strong leadership qualities able to coordinate a team effort is paramount in providing continuity and minimizing the time for project completion.

11) The lack of technical expertise at the local level warrants an educational program so that key actors can make reasonable decisions and, if necessary, choose technically adequate consultants.

The USCM produced a series of 12 community case studies plus two critical issue panel reports. The latest version was updated in March, 1982. The case studies include the cities of:

- Akron, Ohio
- Baltimore, Maryland
- Berkeley, California
- Bridgeport, Connecticut
- Dayton, Ohio
- Fresno, California
- Nashville, Tennessee

- Newark, New Jersey
- North Little Rock, Arkansas
- Port Authority of New York
- Saugus, Massachusetts
- Seattle, Washington

The critical issue reports are:

- Recycling
- Resource Recovery Energy Markets

The case studies provide a detailed analysis and report on the issues affecting the commercial feasibility and performance of the resource recovery options selected by the respective cities. Each contains a summary data page giving salient facts concerning costs, output, general performance, etc. Thus, the complete set provides a good overview of the feasibility requirements for a wide variety of resource recovery systems as well as the underlying data.

X.2.c. Projects in cooperation with the city of New York

X.2.c.1. Feasibility study involving conversion of an existing incinerator to an energy recovery unit

The Department of Energy and DOC decided in 1980 to work with the City of New York to develop a joint project which would enhance economic development by more efficient use of energy. Energy from municipal waste was one of the prime "new" sources of alternate fuel to be considered. NBS/ORM became the technical representative for the entire effort; these responsibilities were assigned by the Associate Deputy Secretary of Commerce with the assent of DOE and NBS management. The basic goal of the project was to develop practical methods to use waste to provide energy to industrial enclaves, e.g., Brooklyn Navy Yard site or Bronx market, and/or to provide supplemental energy for residential district heating. NBS/ORM personnel worked closely with New York City personnel from both the city's Energy Office and from the Department of Sanitation on this project. (The application of RRPLAN to New York City was part of this project as well; see Section IX.4 of this report.)

New York, in company with many large population centers, used incineration--without energy recovery--as a major means to dispose of MSW prior to 1970. But the requirements of regulations associated with the Federal Clean Air Act and companion state statutes forced many of these incinerators to cease operations. However, better air pollution control devices are available now. Furthermore, if these abandoned incinerators could be retrofitted to reclaim energy in a technically and economically sound manner, many community benefits would accrue, e.g., more energy, use of the abandoned facility, more waste disposal capacity, approved site.

Therefore, NBS/ORM and New York City officials agreed that the joint project should thoroughly investigate the feasibility of refurbishing such abandoned incinerators. The Southwest Brooklyn Incinerator was selected by city officials as having the highest priority in terms of need. On September 23, 1982, a detailed report on this feasibility study was submitted to NBS/ORM on behalf of the Department of Sanitation of New York City (for complete citation, see Publications List #99). The findings of this report are summarized in the paragraphs which follow.

The Southwest Brooklyn Incinerator is one of six 1,000 ton per day (tpd) incinerators built by the City of New York in the 1950s. Of these six, only three are presently operating: Betts Avenue, Greenpoint, and Southwest Brooklyn. Each incinerator is equipped with four furnace trains, each designed to process 250 tpd of municipal refuse. The inoperative incinerators include: Hamilton Avenue, South Shore, and Gansevoort.

Both the heating value contained in municipal refuse, which can be converted into useful energy, and the material value of the refuse ash, which can be recovered and recycled into a useful product, offer an opportunity to convert the solid waste into a useful resource and product. The primary purpose of this investigation was to examine both the technical and economic feasibility of exploiting the heating value of the refuse and the material value of the incinerator ash processed at the Southwest Brooklyn incinerator.

Based on the results of field testing, the combustion of municipal refuse at Southwest Brooklyn would be capable of generating 2.2 trillion Btu of energy annually. Enough of this energy could be recovered to produce 93.8 million kWh of electricity, which could supply the annual needs of almost 17,000 homes, or produce 1.2 billion pounds of steam to satisfy the annual heating requirements of approximately 10,000 homes during the heating season.

Quenched incinerator residue is currently transported by barge to New York City's Fresh Kills sanitary landfill on Staten Island. On the basis of a review of market conditions for ferrous recovery and the utilization of incinerator residue as asphalt aggregate, the residue has a potential economic value capable of generating revenues of $1,000-$3,000/day. Materials recovery could offer the additional economic and environmental benefits associated with the reduction or elimination of barging the residue to Fresh Kills.

On the basis of the examination of both the technical requirements and the economics of recovering energy and materials from processed waste, the following conclusions were drawn:

1) The recovery of energy for electricity generation and/or electricity generation with steam production for district heating during the winter months is both technically and economically feasible, and appropriate action should be taken as soon as practical to plan for the preparation of construction contract documents for such an undertaking.

2) There exists an opportunity in the City of New York for the recovery of incinerator ash for use as asphalt aggregate in City-owned asphalt production facilities in Brooklyn. Further testing is required to verify the full potential of ash utilization. Plans for verification should also proceed as soon as practical.

Plans for energy and/or material recovery at the Southwest Brooklyn Incinerator are especially attractive because:

1) The existing furnaces and structures represent a significant portion of the processing systems required for a new refuse-to-energy facility. It is estimated that energy recovery at a new refuse-to-energy facility would require a capital investment greater than twice that of the equivalent energy recovery facility at Southwest Brooklyn.

2) The existing facility eliminates the necessity for comprehensive siting investigations.

3) Local trucking routes have already been established.

4) Additional environmental impacts and licensing requirements are minimal.

5) Energy and material recovery feasibility demonstrated at Southwest Brooklyn can be directly applied to the other operating incinerators at Betts Avenue and Greenpoint, and may be applicable to those incinerators that are presently inoperative.

The technical feasibility associated with energy recovery from Southwest Brooklyn was evaluated by determining the following:

1) Heat content of the refuse, and the energy available for steam generation.

2) Requirements for the control of waste heat boiler corrosion problems.

3) Requirements for the integrated control of boiler/turbine operation for electricity generation.

4) Available district heating market.

5) Total energy output.

A field testing program was undertaken in which flue gas quantities and temperatures were monitored to determine the heat available for steam generation. This eliminated the need to rely on literature values for the heat content of refuse to determine the energy available for steam generation.

A detailed review of potential corrosion problems, and mitigating measures, as well as the expected waste heat boiler operational life, was undertaken to determine process modifications and equipment requirements to minimize the impact of corrosion on heat recovery operation. This evaluation was undertaken by reviewing the literature for corrosion problems associated with municipal refuse combustion, site visits to facilities with dirty gas waste heat recovery applications, and discussions with both European and U.S. waste heat boiler manufacturers concerning operating experiences and recommended operating and design practices.

A comprehensive review of boiler/turbine operation utilizing a fuel with the fluctuating heating value characteristics of municipal refuse was undertaken to ensure that compatible boiler/turbine operation could be effected. This review was integrated into the control systems for the boiler/ turbine operation.

A market survey of potential energy users within a three-quarter mile radius of the incinerator was implemented to determine the available steam market.

An energy availability model was constructed on the basis of energy and equipment availability, and the effect of wet refuse on energy output. On the basis of this analysis, the efficiency of the waste heat boiler and turbine output was projected.

The economic feasibility of energy recovery was addressed by comparing projected revenues against projected costs using revenue projections from New York State Power Pool projected electricity rate schedules and Power Authority (PASNY) projections of oil replacement costs for the steam rate schedule.

Three energy recovery options were evaluated:

1) Generation of electricity only.

2) Cogeneration of electricity with steam distribution to all users within a three-quarter mile radius of the incinerator (full steam loop).

3) Cogeneration of electricity with steam distribution to selected users (partial steam loop).

The installed equipment (capital) cost in 1981 dollars, for each alternative is as follows:

1)	Electricity only	$26,972,000
2)	Cogeneration with steam distribution to all users	$53,082,000
3)	Cogeneration with steam distribution to selected users	$32,309,000

Potential revenues associated with the electricity-only alternative, although less than either cogeneration option, yields the most favorable cash flow forecast. Three deficit years are projected utilizing a rate structure that provides for electrical revenue rates at $0.0770 per kWh in 1986, and escalating thereafter in accordance with New York State Power Pool projections.

The cogeneration-to-selected-user alternative, using Power Authority revenue projections of $10.31 per 1,000 lbs in 1986, is the second most favorable option with only four years of deficit cash flow. This alternative will become more favorable as the area in the vicinity of the incinerator develops and the demand for district heating increases.

On the basis of a review of costs, revenues, and implementation requirements, the electricity-only alternative was recommended for immediate consideration. It was also recommended that this system be designed with the flexibility to incorporate steam or hot water generation for future district heating purposes.

The recovery of ferrous metals from incinerator residue and the utilization of processed residue as aggregate material for bituminous paving mixtures were judged to be the two areas with the greatest potential for market penetration.

Market interest for recovered ferrous material has been expressed by members of the Institute of Scrap Iron and Steel in New York, as well as other ferrous metal dealers.

The New York City-owned Hamilton Avenue Asphalt Plant could provide a reliable market for asphalt aggregate. This plant has a design capacity of 7,200 tpd, as compared to the incinerator's residue generation rate of 200-300 tpd. Residue aggregate processed to specifications could be blended with natural materials for use in asphalt mixtures.

Both ferrous metal and residue aggregate could be recovered with little interference with existing operations. The incinerator residue could be diverted from the existing barge conveyors through rotating screens and magnetic separators to classify residue sizes and separate ferrous materials.

Two recovery concepts were investigated: partial recovery and total recovery.

The installed equipment (capital) cost in 1981 dollars for each option are as follows:

Partial recovery	$796,500
Total recovery	$945,500

On the basis of projections of aggregate replacement costs and/or ferrous resale the partial recovery of ferrous and aggregate from incinerator residue was recommended for further investigation. This alternative could also be modified to provide for total recovery of residue at some future date.

Given the present district heating market at Southwest Brooklyn, generating electricity is the most promising economic alternative. It also is the simplest to implement since it does not require the construction of a distribution system, or negotiations with potential steam customers. In addition, it has the flexibility to incorporate steam or hot water distribution in the future.

With increased development in the vicinity of Southwest Brooklyn, the economics of district heating, with its more efficient utilization of the heat value of the refuse, are likely to become more favorable.

A fourth air pollution control train for furnace No. 1 could be installed at Southwest Brooklyn to meet present air pollution control requirements and to provide the flexibility to operate the incinerator and the waste heat boilers independently.

X.2.d. Conversion of the San Diego County, CA Resource Recovery Recovery Facility to a Solid Waste Research Center

In September 1972, the County of San Diego, California, accepted a $3.8 million grant from the U.S. Environmental Protection Agency (EPA) to demonstrate a flash pyrolysis process developed by a private firm. This firm had previously and successfully conducted bench scale and pilot plant studies of the flash pyrolysis process on municipal solid wastes at their La Verne, California, Laboratory facility.

The demonstration facility, known as the San Diego Resource Recovery Demonstration Facility, was designed to produce a liquid fuel, called "Pyro-fuel," through the process of extracting and pyrolyzing the organic fraction of municipal solid waste, and was also designed to recover substantial quantities of glass, aluminum and ferrous metals for resale to help offset plant operating costs. The facility was complete with electronic truck weight scales, receiving area, shredding area, drying and separating facilities, pyrolysis unit, fuel oil storage tanks, buildings, control room, pollution abatement and associated equipment.

Construction of the demonstration plant at the El Cajon site began early in 1976 and was completed in December of 1976. For the following eight months, the plant underwent "shakedown" procedures to bring all process systems and sub-systems on line into proper operational condition. Demonstration testing commenced on August 16, 1977 and terminated on March 13, 1978.

The San Diego County Resource Recovery plant was designed to process 200 tons/day (181.5 Mg/Day) of municipal solid waste by a flash pyrolysis system to produce 200 barrels of synthetic oil (pyrofuel), 15 tons (13.6 Mg) of ferrous metals, 10.7 tons (9.71 Mg) of mixed colored glass, and 1.2 tons (1.09 Mg) of nonferrous metals (primarily aluminum), all in the same time period. The San Diego Gas and Electric Company contracted with the County of San Diego to purchase the pyrofuel as a suppplemental fuel for one of their existing steam-generating boilers.

Unfortunately, certain difficulties arose during the seven month trial period. Most important was that the flash pyrolysis system did not perform well enough to warrant further commercialization efforts, i.e., technical and economic problems were uncovered. In addition, local markets for the recovered materials were not strong enough to justify further development of these systems.

By 1980 the owner, San Diego County, was prepared to either find some use for the facility or scrap it. NBS/ORM personnel realized that the defunct facility might be made to serve as a research test bed for investigating the commercial feasibility of various resource recovery equipment. Therefore, in partial fulfillment of the mandate of Section 5004 of RCRA, arrangements were made by NBS/ORM to determine if the facility could indeed be used for research purposes.

NBS/ORM, acting under the provisions of the Intergovernmental Personnel Act of 1970 (IPA), arranged for San Diego State University (SDSU) to appoint a Technology Advisor to explore, for a six month period, potential uses for the defunct facility. SDSU appointed Professor Robert Bedore, Chairman of the Mechanical Engineering Department to this position.

Professor Bedore concluded that the San Diego County Resource Recovery Facility could be converted to a research center in six months at an estimated cost of $361,000 plus the cost of new equipment. (San Diego County is willing to lease the facility for use as a research center. The San Diego State University foundation is willing to manage the facility and related research programs.) Appropriate programs would be combustion research, methanol production research, and glass insulation production research. Publications List #123 gives complete details of this effort and summarizes how the various research programs could be used to assess commercial feasibility of resource recovery technology.

If the research center were to be fully developed, there would exist a facility to allow potential buyers and sellers of resource recovery technology to perform full scale pilot plant studies at relatively low cost.

Many of the problems with full-scale solid waste plants are caused by use of unproven technology. The technology is unproven because of the financial, legal, and time constraints which make plant operations unfeasible.

Hence, such a facility would tend to promote proven technology for resource recovery and to perhaps accelerate the process of implementing proven resource recovery projects.

X.2.e. Cooperative efforts with the government of Japan

As part of the scientific interchange program initiated by the United States Government and the Government of Japan, the Department of Commerce was selected by the White House to be the pilot agency for a project concerned with resource recovery from discards originally destined for waste. Such discards include municipal waste and industrial waste. Under terms of the agreement signed by the President and the Prime Minister on May 2, 1980, the United States and Japan will exchange small teams of government scientists in order to examine resource recovery in the respective countries and to formulate possible joint research ventures.

NBS/ORM was designated as the U.S. contact point for this project. The Japanese team visited the U.S. in December, 1981; NBS/ORM arranged the itinerary and provided technical briefings and an overview of resource recovery activities. At that time, NBS/ORM and Japanese representatives concluded an agreement for joint research to be performed as part of the project. Two items were agreed upon:

1) Japan would perform pyrolysis experiments on U.S. supplied refuse derived fuels.

2) U.S. would perform RRPLAN analyses utilizing Japanese technology as the basis for resource recovery. (Appendix XIII contains the complete text of the agreement.)

NBS/ORM arranged to ship to Japan about 35 tons of fluff RDF produced at the Baltimore County, MD resource recovery facility. This material arrived in Japan in early November, 1982. This RDF will be gasified in a paired-bed pyrolysis unit, e.g., a fluidizing mechanism (sand) will be circulated between a pyrolysis reactor and a combustion reactor. Thus, these two reactions occur separately, hence the name "paired-bed."

The gas refining equipment consists of two chains, one for pyrolysis gas and the other for combustion exhaust gas:

1) A cyclone separates char from the gas coming from the pyrolysis reactor. This char is fed to the combustion reactor for burning. After the gas passes through a heat exchanger and is quenched in a carbon deposit protector, a tar-separator removes oil mist and the gas is cleaned in a scrubber. A small portion of this clean gas is pressurized by a blower, preheated in a heat exchanger and used to fluidize the pyrolysis reactor bed; the remaining gas steam is sent to a gas tank for storage.

2) The exhaust gas generated by the combustion reactor is discharged into the atmosphere after being treated by means of a two-stage cyclone and electric dust precipitator. The non-combustible substances contained in the feed stock are discharged from the bottom of the combustion tower periodically.

The RDF will be fed into the system at a rate of 0.6 to 1.0 tons per hour. The pyrolysis reaction temperature is about 650 °C. The following ultimate analyses will be performed:

1) Feedstock

   a. Main components

      C, H, N, Cl, O, Na, K, Ca, Ash.

   b. Harmful components

      Cu, Pb, Cd, T-Hg, As, T-Cr, Al, PCE.

   c. Heat value

2) Pyrolysis gas components

   a. Main components

      H_2, O_2, N_2, CH_4, CO, CO_2, CmHn.

   b. Harmful gas components

      HCl, H_2S, NH_4, HCN, SO_x, NO_x.

   c. Heat value

3) Flue gas

   a. Main gas components

      O_2, N_2, CO, CO_2.

   b. Harmful components

      SO_x, NO_x, HCl, dust.

4) Ash

   a. Main components

      C, H, N, S, Cl, Na, K, Ca.

   b. Heavy metals

      Cu, Pb, Cd, T-Hg, As, T-Cr, Al, etc.

5) Waste water

a. Main components

pH, EOD, COD, SS, n-Hex, Phenol, NH_4^+, Cl^-, CN^-, etc.

Results of the experiment will include:

- o Heat and material balance.
- o Gas and energy recovery rate.
- o Evaluation of the data from public nuisance standpoint.
- o Cost estimation.
- o Final economics.

From these results, the total process flowsheet for a commercial plant, including pretreatment system, will be deduced. Thus, the final output will assess the commercial feasibility of the paired fluidized bed pyrolysis unit under pilot plant conditions. (See Appendix XIII. for details.)

X.2.f. Advisory activities relating to Section 5004 of RCRA

X.2.f.1 NBS/ORM personnel were requested to cooperate with the Department of Energy in selecting projects which would have a high probability of rapid commercialization. The Chief, NBS/ORM and the Manager of TAC personally reviewed well over 100 proposed projects under this program. About seven such proposals were recommended for further DOE consideration.

X..2.f.2 The Chief, NBS/ORM served as a technical advisor to a National Academy of Sciences/National Research Council effort concerned with evaluation of technology meant to deal with hazardous wastes. The report of this work was released in early 1983. (Publication NMAB-398, 76 pp, 1983)

X.2.f.3 The Chief, NBS/ORM provided technical input to a NATO/CCMS study concerning co-disposal of urban waste and sewage sludge. The objective was to compare mass-burning methods, widely used in Europe, with a U.S. technology embodying RDF as the fuel source. Mass burning was more efficient.

XI. PILOT PROGRAM WITH THE CALIFORNIA STATE SOLID WASTE MANAGEMENT BOARD

The NBS/ORM cooperative efforts with the Association of State and Territorial Solid Waste Management Officials were in part concerned with state measurement needs. Results indicate that even though state programs vary with regard to stringency of regulatory requirements, state measurement needs are similar in hazardous waste. Resource recovery measurement needs identified in Subtitle D do not exhibit the same level of priority as those under Subtitle C--Hazardous waste program. Nevertheless, standard analytical methods, protocols, and procedures specified in state regulations match those methods cited in Federal criteria. Development of standard laboratory and field methods for sampling and analyses as well as standard reference data are required. The lack of availability for such measurement tools is severely impeding national consistency on a State-to-State basis, timely program implementation, and worker protection and safety. Consequently, a formal manual of operating procedures is necessary to assure not only State-to-State programmatic and enforcement consistency, but also intra-state field and functional laboratory activities. Standard laboratory certification and quality assurance programs do not exist and would be helpful in attaining State-to-State consistency. Lastly, training programs and technical assistance for laboratory and field personnel may be inadequate at state level. As part of its continuing commitment to working with State and local government, NBS assigned a senior staff member to work with the State Solid Waste Management Board (SSWMB) in California. The purpose of this Intergovernmental Personnel Agreement was to provide an interface between perceived State measurement needs and NBS expertise.

The SSWMB is required under California law to deal with all aspects of solid waste management and to strongly emphasize resource recovery, recycling and reuse of materials destined for waste. Conservation and waste reduction are also under the purview of the SSWMB. Since a number of SSWMB's programs were similar to NBS/ORM mandates, mutual efforts were decided upon.

The following general project areas were chosen for cooperative work:

1) Procurement of recyclables and markets for such products in California.

2) Technology transfer of RRPLAN to selected regions of California, e.g., Fresno and Ventura Counties; Fresno was provided with a comprehensive analysis via RRPLAN in April, 1983.

3) Measurement requirements to characterize potentially hazardous wastes.

4) Technical advice regarding waste-to-energy systems, e.g., San Diego County.

5) Markets and use for fly ash.

6) Specifications for recovered materials.

A series of reports describing progress in each of these areas was prepared by the NBS/ORM representative. These reports are available; see Publications List #122. Basically, the results enabled NBS to better focus its efforts to provide test methods, standards, and other measurement services to the States. Hence, the State received the direct benefit of the NBS/ORM representative while NBS was able to increase the efficiency of its services with respect to waste management and other environmental measurements.

XII. BRIEF SYNOPSES OF OTHER ACTIVITIES

The Chief, NBS/ORM organized and chaired the DOC Intragency Group on RCRA Related Activities. Virtually every agency and bureau within DOC was represented. This Group coordinated all DOC activities relating to RCRA; NBS/ORM provided technical assistance to every area of DOC having projects concerned with resource recovery, recycling and reuse of materials. The Group functioned from February 1980 to mid-1982.

NBS/ORM co-sponsored two resource recovery research needs seminars with the National Center for Resource Recovery. The object was to bring together groups of scientists who could suggest new research tools for resource recovery.

The Chief, NBS/ORM served as advisor to the Intergovernmental Science, Engineering and Technology Applications Panel of the White House Office of Science and Technology Policy. This panel sponsored intensive research needs development meetings concerned with urban waste and hazardous waste.

Departmental testimony before the U.S. Congress was required on eight occasions; both EPCA and RCRA responses were required. NBS/ORM personnel prepared the basic written statement of Departmental witnesses on all of these occasions. NBS/ORM staff also testified directly on four occasions.

Subtitle H of RCRA created a Cabinet level Resource Conservation Committee charged primarily with examining, (1) beverage container deposit legislation and (2) product charges meant to fully internalize waste costs for the discarding person or firm (polluter pays equity principle). The Chief, NBS/ORM provided review, advice, and technical analysis to the DOC representative on the Committee. Analysis indicated that, on the Federal level, neither of the two proposals before the Committee were appropriate. Other Committee members agreed.

Subtitle D of RCRA required the Bureau of the Census of DOC to aid in a survey of open dumps in the U.S. Specifically, Section 4005(b) of the Resource Conservation and Recovery Act of 1976 requires that the Administrator of the Environmental Protection Agency (EPA) "with the cooperation of the Bureau of the Census' publish an inventory of "all disposal facilities or sites in the United States which are open dumps within the meaning of" the Act. Under the provisions of the Act, regulations prescribing the criteria for classifying facilities as open dumps were to have been promulgated not later than October 1977, with publication of the inventory not later than October 1978. However, the technical complexity of solid waste disposal and its effect on the environment, as well as legal requirements for consulting with the States and conducting public hearings, prevented promulgation of regulations within the time period prescribed by the Act. In the course of ensuing legal action by the State of Illinois and three environmental groups, EPA negotiated revised dates for all deadlines established by the Act. Final regulations under Section 4004 covering solid waste disposal were promulgated on September 13, 1979, in the Federal Register.

The development of the inventory did not involve data collection activity by the Bureau. The inventory was derived from information submitted by State officials including facility identification, code, name, location, ownership, and type, plus an indication of the criteria used to classify the facility as an open dump. The Census Bureau, under an interagency agreement, was responsible for processing the data submitted by the States and for preparing the inventory list for publication. The Bureau assisted EPA in the development of the form used by the States in reporting open dumps, the facility identification code system, geographic reference materials, and publication formats for the inventory list and attendant tabulations. The Open Dump Inventory was published in 1981.

XIII. AMENDMENTS TO RCRA (PL 96-482)

In 1980, the Congress amended RCRA considerably. The bill that Congress passed was signed into law on October 21, 1980 by the President as PL 96-482. There were no substantive changes in Sections 5001, 5002, 5003, and 5004 of Subtitle E. However, Subtitle E was amended by inserting the following new section after Section 5004:

> "SEC. 5005. In establishing any policies which may affect the development of new markets for recovered materials and in making any determination concerning whether or not to impose monitoring or other controls on any marketing or transfer of recovered materials, the Secretary of Commerce may consider whether to establish the same or similar policies or impose the same or similar monitoring or other controls on virgin materials."
>
> (2) The table of contents for such Act is amended by inserting the following new item after the item relating to section 5004:
>
> "Sec. 5005. Nondiscrimination requirement.". (42 USC 6955)

Responsibility for implementation of Section 5005 was not delegated to NBS/ORM. Therefore, NBS/ORM did not deal with any activities pursuant to Section 5005 at any time.

XIV. CONTRIBUTIONS OF ORM TO THE INSTITUTIONAL HEALTH OF NBS

Any programmatic effort at NBS should contribute strongly to the basic competence of the Bureau. Thus, scientific and technical contribution was always a goal of the managers of ORM as they decided on specific aspects of the technical research projects. A brief listing of new NBS competences developed as a direct result of the ORM programs includes, but is not limited to, the following:

- Macrocalorimetric capabilities and equipment unsurpassed in the world;
- A mature tribochemistry competence;
- A new algorithm for operations research models;
- Improved combustion chemistry competence;
- New contributions to trace inorganic and organic chemicals analysis, e.g., PCBs in oil; and
- New SRMs, e.g., synthetic leachate, PCBs in oil.

Thus, while ORM formally ceased operations on September 30, 1982, these and other competences developed during its lifetime will continue to contribute to the strength of NBS.

APPENDIX I

DIRECT PUBLICATIONS OF THE OFFICE OF RECYCLED MATERIALS (ORM)

ORM PUBLICATIONS IN THE OPEN LITERATURE

(Listing is Current to August 8, 1983)

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17. Health, D., Franklin Institute, Development of a Bench Engine Screening Test for Motor Oil, Fourth Conference on Measurement and Standards for Recycled Oils, September 14-16, 1982.

18. Becker, Donald A., and Hsu, Stephen, NBS Provisional Tests for Re-refined Engine Oil, Fourth Conference on Measurement & Standards for Recycled Oil, September 14-16, 1982.

19. Klaus, E., Shah, P., and Krishnamachar, V., Pennsylvania State University, Development and Use of the Micro-Oxidation Test with Crankcase Oils, Fourth Conference on Measurement and Standards for Recycled Oil, September 14-16, 1982.

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ADDENDUM TO APPENDIX I. NBS RESEARCH REVIEW ON THE CHARACTERIZATION OF MUNICIPAL SOLID WASTE

(September 13, 1983)

National Bureau of Standards

Gaithersburg, Maryland

Cochairmen: Eugene S. Domalski, Chemical Thermodynamics Division
National Bureau of Standards

Christopher A. Kouts, Energy from Municipal Waste Division
Department of Energy

The purpose of the one day research review was to report the results of characterization studies on municipal solid waste (MSW) and refuse-derived fuels (RDF) carried out at NBS under the sponsorship of the U.S. Department of Energy, Office of Renewable Technology, Energy from Municipal Waste Division.

The significance and impact of sample processing, particle size distribution, sample variability, representativeness of gram-size and kilogram-size samples, and the thermal characteristics of such samples was discussed. In addition, quantitative measurements and methodologies characterizing MSW and RDF for the more efficient thermal conversion of such feedstocks to energy and/or useful products were presented. Papers were presented on potential mechanisms of formation and the subsequent destruction of trace organic pollutants in the MSW combustion process.

The research review included a tour of the large sample (2.5 kilogram) calorimeter used by NBS in MSW research.

Review Agenda

Program

Entrainment Flow Combustion of RDF Particles
A Macek and S. R. Charagundla

Corrosion Studies in MSW-Fired and Coal-Fired Boiler Systems
E. Escalante

Development of a Synthetic RDF as a Standard Reference Material
J. C. Colbert and E. S. Domalski

Significance of Experimental Data from a 2.5 Kilogram Capacity Flow Calorimeter
K. L. Churney, A. E. Ledford, Jr., M. L. Reilly, S. J. Skidmore, and E. S. Domalski

Variability of Sulfur and Chlorine Content in MSW and RDF
S. Abramowitz, J. C. Colbert, D. R. Kirklin, and E. S. Domalski

Characterization of RDF During Various Stages of Processing
D. R. Kirklin, P. H. Decker, and E. S. Domalski

Enhancement of the Calorific Value of RDF by Aluminum and Iron
J. C. Colbert, D. R. Kirklin, and E. S. Domalski

RDF Characterization Using Thermal Methods of Analysis
J. A. Walker and W. Tsang

Hazardous Waste Aspects of Municipal Solid Waste Incineration
W. Shaub and W. Tsang

Tracers for Quality Assurance in Municipal Solid Waste Incineration
W. Tsang and W. Shaub

APPENDIX II. SELECTED ABSTRACTS FROM CONFERENCE ON MEASUREMENTS AND STANDARDS FOR RECYCLED OIL-IV

Held

September 14-16, 1982

National Bureau of Standards
Gaithersburg, Maryland

Sponsored by:

Recycled Oil Program
National Bureau of Standards
U.S. Department of Commerce

ASTM Technical Division P, on
Recycled Petroleum Products

Association of Petroleum Re-Refiners

ANALYSIS FOR PCBs IN OIL: TECHNIQUE AND SRM DEVELOPMENT

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Polychlorinated biphenyl (PCB) mixtures (Aroclors) are toxic global contaminants that have been extensively used as electrical transformer fluids in this country. A hybrid technique utilizing high-performance liquid chromatography (HPLC) and capillary column gas chromatography (GC) has been developed for the determination of polychlorinated biphenyls in hydrocarbon matrices, such as transformer and motor oils. This method first employs preparative-scale HPLC to remove the major portion of analytical interferences from the oil sample. The "clean" sample is then analyzed using a nonpolar wall-coated open-tubular GC column and electron capture detection for identification and quantitation of any PCB contaminants. Quantitative data are obtained by relating peak areas of internal standards(s) (here, PCB congeners not detected in the Aroclor of interest) to the areas of the PCB peaks of samples and of calibration standards.

Samples of used motor oils containing a wide range of concentration and type of PCB contamination have been analyzed using this method. This procedure has also been used to certify a Standard Reference Material (SRM 1581) entitled "Polychlorinated Biphenyls in Oil" that consists of separate solutions of Aroclor 1242 and Aroclor 1260, each in a transformer oil and a motor oil base at the 100 ppm (wt./wt.) level. The SRM is designed to be used as an external standard for analytical calibrations as well as a benchmark for interlaboratory comparisons. The method used should be easily adaptable to other laboratories as it employes the use of conventional, commercially available instrumentation, columns, and detectors. We have found it to give accurate analysis of samples containing as little as 1 ppm total PCB concentration.

ANALYSIS FOR PCBs IN OIL: THE ASTM/NBS ROUND ROBIN

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Early in 1982, a cooperative effort on the analysis of polychlorinated biphenyls (PCBs) in oil was initiated by the National Bureau of Standards (NBS) Recycled Oil Program and the American Society for Testing and Materials (ASTM), Section II (Used Oils and Basestocks) of Technical Division P (Recycled Petroleum Products). The primary purpose of this cooperative effort was to help provide the necessary information and data to identify an accurate, relatively simple method for the analysis of PCBs in oil, with subsequent consideration for development into an ASTM Standard Method. A secondary purpose was to help oil recyclers identify an analytical methodology which could be utilized to obtain reliable PCB analyses.

The round robin consisted of eleven (11) samples of oil in sealed glass ampoules which contained one or more of the Aroclors at known (by NBS) concentrations. Seven of these samples (A - G) were made with known quantities of Aroclor(s) dissolved in a virgin lubricating base oil (i.e., gravimetric values), including two duplicates. The remaining four samples were a re-refined base oil with known PCB content (H), two used engine oils with PCBs added (I, J), and a re-refined base oil with an additive package suspected of causing interferences with some PCB analytical methods.

A total of eighteen (18) laboratories cooperated by supplying analyses of the samples using their own procedures. Since our laboratory analyzed the samples by two methods, a total of nineteen (19) sets of results were obtained. In addition, all laboratories were requested to provide a copy of their procedure(s), and most complied although there was a wide discrepancy between the completeness of the various procedures supplied.

The results of the interlaboratory round robin will be presented along with statistical analyses of the data in an attempt to identify the method(s) providing the most accurate results. As an example of the kind of results that were obtained, sample C (known concentration of 148.3 μg/g of Aroclor 1260) had results averaging 121 ± 96 μg/g (± value is 95 percent Confidence Interval; n = 1 with a range of 31 μg/g to a high of 243 μg/g.

DEVELOPMENT OF METHODOLOGY FOR ENGINE DEPOSIT CHARACTERIZATION*

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A method was needed for comparison of engine deposits formed under varied conditions and/or with different oils. The method developed involves removal of deposits from three distinct areas of a piston: (1) the skirt, oil ring, and groove area; (2) the crown and the compression rings, grooves, and lands area; and (3) the undercrown area. Deposits were removed with a mixture of toluene-acetone-methanol (TAM) and dimethylformamide (DMF) which allows simultaneous removal of both oily deposits and high molecular weight polar residues. Deposits were recovered by evaporation of solvent, then extracted sequentially with increasingly polar solvents and filtered to remove insoluble residue. Heptane, toluene, TAM, and DMF soluble fractions and insoluble materials were concentrated and recovered by solvent removal. The recovered deposit fractions were then analyzed for each of the three areas of the piston. Any analyses desired could be performed on recovered fractions for comparison purposes. AFLRL analyses included infrared spectroscopy, carbon, hydrogen, nitrogen, and sulfur content, and molecular weight determination. Qualitative X-ray fluorescence analysis for other elements was performed on soluble fractions. Insoluble fractions were analyzed quantitatively.

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*Work sponsored by ROP-NBS/ORM

THE ASTM/NBS BASESTOCK CONSISTENCY STUDY

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Early in the National Bureau of Standards (NBS) work on recycled oil, it became clear that the most important requirement for assuring the quality of re-refined engine oil was the development of a set of test procedures capable of monitoring the consistency and additive response of a re-refined oil basestock, inbetween qualifications of the formulated oil through use of the ASTM engine sequence tests.

In 1979, NBS proposed to ASTM Technical Division P that a cooperative basestock consistency study be initiated, in which as many tests as possible are used to characterize monthly production samples from both re-refining companies as well as virgin refiners. This effort was approved by ASTM in June of 1979.

The ASTM/NBS Basestock Consistency Study (BCS) was initiated in early 1980, when four virgin oil producers and six re-refined oil producers submitted monthly samples of their regular production basestock for analysis by a group of 14 laboratories. The production samples were provided to NBS, then subdivided and coded before transfer in groups (including a control sample) to the analyzing laboratories. These laboratories analyzed the samples using over 40 different chemical, physical, and performance tests.

The data contained in the report of this study is a compilation of the results from these tests, on 13 monthly production samples from each oil. The data has been statistically evaluated, and for many tests the results have been graphed using one or more techniques, in order to better visualize the relative consistency of the oils and/or test data.

The data generated in this study is thought to be the most comprehensive ever obtained on re-refined lubricating basestocks, and has been used extensively by NBS in the evaluation of tests for re-refined oil basestock consistency.

Grateful acknowledgment is also made to all of the manufacturers, analyzing laboratories, and coordinators who have contributed so much to this study. It is hoped that all of the tremendous effort represented here will be useful to many people, for multiple purposes, for many years to come.

MULTIPLE REGRESSION ANALYSIS: A LOOK INSIDE ASTM/NBS BCS DATA

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The selection of basestocks to be refined into finished product lubricating oils has been historically determined using a variety of standardized bench, pump and engine tests. The first phase of the ASTM/NBS Basestock Consistency Study (BCS) evaluated test procedures with regards to the consistency of the feed stock question. This second phase of the program is an attempt to correlate the physical and chemical properties with the performance bench tests.

Beginning with the fundamental axion: the data analyst knows more than the computer; performance tests were selected as the responses and a subset of physical and chemical properties as the candidate regression variables, and interactive computing and exploratory methods were used to look for features in the data.

The results obtained show the 'best' correlations for the examples chosen. Depending on the known relationship of the selected performance test in predicting the results of the full-scale engine and tests, the physical and chemical property tests determined to give the most predictive powers in determining the performance test results can then be used as quideposts in selecting high quality basestocks.

COMMENTS ON TEST METHODS FOR PHYSICAL PROPERTIES OF RE-REFINED LUBRICATING BASESTOCKS

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Physical property measurements are routinely performed on lubricating basestocks to assure quality control. In the past, refiners could control the feedstock source as well as the refining process to ensure product quality. Re-refiners need to establish (1) the applicability of available test methods to re-refined base oils and, (2) the range limits of physical properties for their products.

Re-refined base oils from various re-refining processes in the U.S. were selected. Existing test methods were evaluated and modified when necessary. The following tests were established as being applicable to re-refined base oils: Boiling point distribution by GC, kinematic viscosity, density, refractive index, flash point, pour point, API gravity, and color. In addition, derived properties, such as viscosity index and hydrocarbon type distribution by n-d-m, were calculated.

COMMENTS ON TEST METHODS FOR CHEMICAL CHARACTERIZATION OF RE-REFINED BASE OILS

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Standard test methods used to determine several characteristics of lubricants were applied to re-refined lubricant basestocks, and the results evaluated. Modifications in some test procedures were necessary in order to make the methods suitable for these oils. The characteristics that were measured included total acid number (TAN), total base number (TBN), total nitrogen, basic nitrogen, saponification number, and water. The modified procedures were applied to a variety of commercially available re-refined oils and the values tabulated.

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EVALUATION OF ASHING METHODS FOR DETERMINATION OF TOTAL METAL CONTENT OF LUBRICATING OIL BASESTOCKS

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Ash for a petroleum oil may be defined as the residue, free of carbonaceous material, remaining after burning and ignition in air at a specified high temperature. In the case of re-refined base oils, ash content provides a simple method for the determination of total metal content resulting from wear or additive metals remaining after re-refining.

Three ashing methods were evaluated for volatile metal retention. The sulfated ash method was found to have good metal retention properties, and was modified to improve its precision in the low ash range.

The sulfated ash contents of ten re-refined stocks, representing all major U.S. re-refiners, ranged from 0.005 percent to 0.017 percent. The majority of the virgin stocks had ash values below 0.005 percent.

DEVELOPMENT OF A STEP LOADING SEIZURE TEST FOR ENGINE OIL ADDITIVE RESPONSE

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Additive response measures the effect of base oils on the performance of an additive or combination of additives. This study is concerned with measuring the effect of basestock composition on the antiwear performance of an engine oil additive package.

Two step loading seizure four-ball wear test procedures were investigated for measuring additive response using an engine oil additive package and a set of seventeen base oils. The procedures examined were a conventional step loading seizure test which uses 10 ml sample, a microsample step loading seizure test which uses only six microliters sample and combines oxidation and wear in a single test. Both tests have been shown to correlate with engine wear experience. The conventional step loading seizure test was not suitable for additive response determinations at high (8.0 percent) additive package concentrations. The microsample step loading seizure test was able to measure a difference in additive response among the base oils at 8.0 percent additive package.

This microsample step loading seizure test affords an opportunity to measure the additive response of a larger set of base oils in an attempt to determine the individual components within the basestock which affect the antiwear performance of the lubricant.

DIFFERENT SCANNING CALORIMETRY TEST METHOD FOR OXIDATION STABILITY OF ENGINE OILS

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A laboratory bench oxidation test has been developed which measures oxidation stability of automotive crankcase lubricants under simulated engine conditions. The test employs a high-pressure, differential scanning calorimeter (DSC) to measure oxidation induction times in thin-film oil samples at 175 °C in 3.6 MPa oxygen. Engine chemistry is simulated by mixing the oil sample with oil-soluble metal naphthanates and oxidized nitrated gasoline. The DSC test ranks the relative oxidation stability of seven ASTM engine sequence IIID reference oils in the same order as the engine test does. The bench test requires less than an hour's time to perform, uses only 1 mg of sample, with an average 6 percent repeatability. Details of method development are discussed.

COMPARATIVE RESPONSE OF RE-REFINED AND VIRGIN LUBE OILS TO ADDITIVES BY DSC

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Earlier studies have demonstrated the capability of high pressure differential scanning calorimetry (HPDSC) in determining the propensity towards autoxidation of lubricating oils. This report is an extension of previous work and is focused on the following issues:

(a) The consistency of basestocks produced over the course of a year, with special reference to the similarities and differences between recycled and virgin bases.

(b) The effect of the various components in the additive mixture on the intensity and time for response.

(c) The response of various components of the base oilstock towards a particular additive.

(d) The response of basestocks to different additive packages.

Our results are consistent with the assumption that differences between virgin and re-refined basestocks are no larger than that between virgin bases. Appropriate additives can ameliorate such differences. The variation in oxidative properties for samples of virgin and re-refined basestocks prepared over a period of time were similar. The polar and aromatic fractions in basestocks contain the active ingredient that interact with the antioxidant. With respect to the additive, both detergent and dispersants have effects on autoxidation properties. Addition of calcium phenate result in dramatic increase in heat effects and serves to increase the sensitivity of the method.

LUBE BASE OIL CHARACTERIZATION USING LIQUID CHROMATOGRAPHIC TECHNIQUES

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A separation scheme for lubricating base oils into molecular compound classes has been developed. The isolated compound classes were tested for new insight and information linking basic hydrocarbon molecular structures to oxidation stability could be gained.

The separation scheme separates the oil into three major fractions; saturates, aromatics and polars using clay-gel liquid chromatography. The saturate fraction consists mainly of paraffinic anc cyclic paraffinic hydrocarbons. The aromatic fraction comprises of mono- and poly-aromatic compounds. Both poly-nuclear aromatic compounds and hydrocarbons with hetro atoms such as sulfur, halogens, and oxygen are present in the polar fraction. The polar fraction is further separated into compound classes of different polarities and functional structures. Spectroscopic methods such as infrared and mass spectroscopy were used to elucidate the functional structures of each compound class.

The oxidation stability of each major fractions and compound classes are tested with the micro-oxidation test. Of the three major fractions of the lubricating base oils, only polar fraction has the highest anti-oxidant capacity values in comparison to saturate and aromatic fractions. Among, the compound classes in the polar fraction, the amine and phenol fractions have high anti-oxidant capacity value in comparison to other classes.

EVALUATION OF ASTM D-2007 METHOD FOR DETERMINATION OF LUBE BASE OIL COMPOSITION

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ASTM D-2007, "Characteristic Groups in Rubber Extender Oil by Clay-Gel Adsorption Chromatography," and its variations were evaluated for lubricating base oils, both virgin and re-refined. Results from D-2007 are compared with those obtained from the n-d-m method and low resolution mass spectroscopy. D-2007 is found to be applicable to lubricating base oils and offers a rapid analytical procedure for hydrocarbon type analysis for both virgin and re-refined base oils of various viscosity grades. Hydrocarbon types such as polar compounds, aromatics, and saturates from various base oils are separated using D-2007 and the fractions are characterized using infrared spectroscopy, refractive index, etc.

TEST METHODS FOR TOTAL CHLORINE IN LUBRICATING BASE OILS

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Chlorine is usually absent in virgin lubricating base oils (usually less than 2 ppm). However, in re-refined lubricating oils, chlorine usually is present at 5 to 10 ppm, a few base oils have chlorine content as high as 1000 ppm. The effects of the chlorine on performance are not clear. However, for consistency monitoring of re-refined base oils, an accurate method to determine the chlorine content is desired.

Five analytical methods were studied. They are ASTM D-808 method; Chlorine in New and Used Petroleum Products (bomb method), ASTM D-1317 method; Chlorine in New and Used Petroleum Products (sodium alcoholate method), X-ray Fluorescence Method (XRF), Neutron Activation Analysis (NAA), and micro coulometric titration method.

Both ASTM methods have a low applicability limit of 100 ppm which is higher than the usual chlorine concentration in re-refined base oils. Thus they are not applicable. Modifications of these two methods to lower limits were unsuccessful.

XRF method has a low applicability of 5 ppm which is above the chlorine content in virgin base oils. The remaining two methods, NAA and microcoulometric titration method are suitable for the determination of chlorine content in the base oils. The applicability range of NAA is from 1 ppb to 100 percent and of the microcoulometric titration method, the range is 1 ppm to 1 percent. The precision of NAA is ± 0.2 percent and microcoulometric titration method, ± 10 percent.

A THIN-FILM OXYGEN UPTAKE TEST FOR THE EVALUATION OF AUTOMOTIVE LUBRICANTS

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A thin-film, oxygen absorption test has been developed for the evaluation of automotive lubricants using a standard Rotary Bomb Oxidation Test apparatus (RBOT) with simple modifications. The test measures the induction time of the lubricant under test conditions which simulate high temperature oxidation processes in automotive engines. Effects of oxidized fuel components and metal catalyses as well as the effect of hydrolysis on oil oxidation were considered. Test results on the ASTM engine sequence IIID reference oils suggested qualitative correlation with engine viscosity increase data. Additional commercial oils were also tested and the results fell within the reference oil ranges.

THIN-FILM OXIDATION TEST: RELATIONSHIP BETWEEN CHEMICAL COMPOSITION AND ADDITIVE RESPONSE FOR RE-REFINED OILS

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Sixteen re-refined lubricating base oils from different manufacturing processes were examined for oxidation stability with an NBS developed thin film oxygen uptake test. The oils were tested with a commercial SE/CC DI additive package. Possible correlation between oxidation stability and chemical composition parameter such as saturates, aromatics, polars sulfurs, and total nitrogen contents were investigated. Key composition parameters to oxidation stability are identified.

NBS PROVISIONAL TESTS FOR RE-REFINED ENGINE OIL

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This paper describes results which complete the second and final phase of the NBS efforts on recycled oil. Test procedures are described which NBS is recommending for establishing the substantial equivalency of re-refined engine oil to virgin engine oil. The strategy that NBS has adopted first calls for the formulated oil quality to be determined by means of all currently required industry tests. After the quality of the formulated re-refined oil has been established through use of these tests, the consistency of the re-refined oil basestock is to be monitored as a function of time through use of the tests described in this paper. Re-refined oils designed to meet the various industry-accepted performance levels would require testing levels concomitant with those required for virgin oils. The NBS provisional tests for re-refined basestock consistency include a number of test procedures for chemical and physical characteristics, plus a bench test for oxidation stability.

With respect to the provisional testing system described in this paper, a period of validation of these tests is necessary before full implementation. That is, a controlled application of these tests to re-refined oils over a period of time is needed to ensure that they are completely capable of fulfilling the requirements of consistency monitoring. Upon completion of such a validation process, the provisional re-refined engine oil testing system as described can be accepted for indicating that a re-refined engine oil product is substantially equivalent to virgin engine oil.

APPENDIX III. DIOXIN FORMATION IN INCINERATORS

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Abstract

Processes which may contribute to the formation of polychlorinated dibenzo-p-dioxins (PCDDs) in incinerators are examined. A model mechanism has been constructed to investigate the possibility of homogeneous gas phase formation of PCDDs from polychlorinated phenols in an incinerator environment. Numerical calculations have been made. The results lead to the conclusion that the probability of gas phase formation of PCDDs is likely to be very low at high temperatures if mixing between fuel and air is efficient. Probable sources of non-idealities in practical incinerators are examined. Effects of use of auxiliary hydrocarbon fuel and excess air are examined. The potential role of non-gas phase effects is considered. A discussion of some of the significant problems which complicate a further understanding of PCDD formation processes in incinerators has been presented in a manner that highlights future research needs.

Introduction

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have been reported to have been found in incinerator emissions and other combustion sources [1,2][1]. It has been suggested that these chemicals may be ubiquitous as a consequence of trace chemical processes that occur during combustion [3]. This is a controversial question (4a, b). With respect to their formation in municipal incinerators, it has been suggested that likely major routes of formation are from chemically related compounds such as chlorinated benzenes, chlorinated phenols and PCBs [5]. There appears to be uncertainty as to the relative importance of formation from non-chlorinated precursors and inorganic forms of chlorine or from chemically unrelated chloro-organic compounds such as polyvinyl chlorides [5]. Laboratory experiments which deal with the formation of PCDDs and PCDFs from polychlorinated phenols, polychlorophenates, polychlorobenzenes and PCBs have been reported [1,2,4b,6,7]. Most observations concerning the formation of hazardous waste compounds such as PCDDs during thermal incineration are fundamentally qualitative in nature in the sense that they do not provide detailed answers which can lead to process modifications that may minimize the formation of PCDDs. None of the experiments [1,2,6,7] which have been reported to date can be considered to be adequate to demonstrate that the compounds (PCDDs, PCDFs, etc.) which have been observed to form are attributable to gas phase processes [8,9]. In addition, we have previously suggested that in some instances there seems to be evidence that formations reported in some laboratory experiments may in fact be due at least in part to surface reactions [10,11]. There is a substantial body of literature in which it has been explicitly demonstrated that reactions involving chlorinated species are frequently affected or controlled in whole or in part by the presence of reactive surfaces [8,12-27].

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[1] Figures in brackets indicate the literature references at the end of this paper.

In the following discussion we will examine some aspects of these problems by first considering the potential for gas phase formation under strictly homogeneous conditions in order to establish a frame of reference. We draw upon existing information about gas phase reaction processes to develop a reasonable mechanism for gas phase formation of PCDDs from a suggested precursor, polychlorinated phenols [2]. Next, we examine some possible gas phase non-idealities which may develop during thermal incineration. This will be followed by a consideration of potential non-gas phase contributions. Some general conclusions will be drawn regarding the problem of understanding PCDD formation in incinerators.

Mechanism Construction

The reaction steps which make up the proposed gas phase mechanism, discussed below, are shown in table 1. The species denoted P, P·, PD and D respectively represent polychlorinated phenols, polychlorinated phenoxy radicals, polychlorinated 2-phenoxyphenols (dioxin precursor [2]) and PCDDs. These compounds are shown in figure 1, where Cl_x and Cl_y denote the varying extent of chlorination of the compounds. In table 1, the species denoted by the symbol, R, represent any other organic fuel compounds in the gas phase mixture. R· and Pr respectively denote a fuel molecule from which a hydrogen atom has been abstracted and unspecified products. In Figure 2, the pathways of the proposed mechanism are shown schematically.

The rate constants assigned to the steps in the mechanism have been given values similar to rate constants which have been reported in the literature for analogous reactions. However, where there are uncertainties, the numerical values have been adjusted somewhat to bias the mechanism in favor of PCDD formation i.e., worse case modeling.

Each of the reaction steps as given in table 1 is discussed below. The assigned rate constants have been biased to favor PCDD formation. Therefore the reader is strongly cautioned not to use these estimates out of the context of this paper, as actual values for these rates will be quite different in some cases. The reaction,

$$P \rightarrow P\cdot + H \qquad (R1)$$

represents the simple unimolecular bond rupture of the weakest bond in a polychlorinated phenol. The activation energy for this step is taken as the O-H bond energy in phenol, which has been determined experimentally [28]. Chlorine substitution is not expected to affect substantially this value [10]. The pre-exponential factor is assigned a value comparable to that associated with the formation of benzyl radical from dissociation of toluene [29] as a reasonable estimate. Thus, $k(R1) \approx 10^{15.5} \exp(-86000/RT)\ s^{-1}$.

The reaction,

$$OH + P \rightarrow P\cdot\ H_2O \qquad (R2)$$

represents the process of hydrogen atom abstraction by hydroxyl radicals. In high temperature combustion such as incineration, the hydroxyl radical is the most important small inorganic radical present under typical incinerator operating conditions [10,11, 30-34]. Furthermore, there is evidence that a local thermodynamic equilibrium between small inorganic radicals rapidly develops in the combustion flame zone [10,11,34]. A temperature dependent hydroxyl radical concentration can therefore be estimated from the local equilibrium assumption. In addition, we have previously estimated a bimolecular rate constant of $\approx 10^9\ L\cdot mol^{-1}\cdot s^{-1}$ for hydroxyl radical attack on PCDDs [10]. The mechanism uses the value of $\approx 10^9\ L\cdot mol^{-1}\cdot s^{-1}$ for this reaction, and is biased in favor of PCDD formation by ignoring the addition reaction of OH to polychlorinated phenols, even though OH addition to aromatic compounds is known to occur [30,36-38]. The adduct from OH addition may simply decompose back to the original reactants, or undergo further reaction with molecular oxygen or other species present in the combustion system, leading eventually to ring opening [10,28, 35,36], a process which would not be expected to favor PCDD formation. Note also that the electrophilic nature of OH attack in addition reactions leads to a drastic lowering of the rates with increasing halogenation and that addition reactions usually decrease in rate as the temperature is increased [30].

The reaction,

$$P\cdot \rightarrow Pr \qquad (R3)$$

represents the decomposition of the phenoxy radical, resulting in elimination of CO, which has been observed to occur [28,39]. The assigned rate constant, $k(R3) \approx 10^{13.6} \exp(-57654/RT)\ L\cdot mol^{-1}\cdot s^{-1}$ follows from analogy to the results of Colussi, Zabel and Benson [28].

The reaction,

$$P + P\cdot \rightarrow PD + Cl \qquad (R4)$$

represents the formation of a PCDD precursor, a polychlorinated 2-phenoxyphenol. In order to bias the mechanism in favor of PCDD formation, the possibility of reaction at other than the 2 position is ignored. Reaction at other than the 2 position has been reported, although not explicitly for the gas phase [40,41] and may ultimately lead to polymerization in some instances. The rate of this bimolecular reaction, (R4), is probably very slow with a very small steric factor and possibly a negative temperature dependence

[10,42]. It is probably slower than the hydrogen abstraction reaction, (R7),

$$P\cdot + R \rightarrow P + R\cdot \qquad \text{(R7)}$$

Mulcahy and co-workers [43] have reported (for the unsubstituted phenol) that the reaction

$$CH_3 + P \rightarrow CH_4 + P\cdot$$

has an activation energy barrier of $E_A \approx 8\pm2$ kcal·mol^{-1}. Since $\Delta H^\circ_{298} = 17.8$ kcal·mol^{1} for the reverse of this reaction [10,44, 45], the activation energy for the reverse of this reaction may be estimated to be about 26 kcal·mol ^{1}. Therefore, by analogy, to bias the mechanism in favor of PCDD formation, we assign to the rate constant for reaction (R7), a value of $k(R7) \approx 10^8 \exp(-26000/RT)$ L·mol^{-1}·s^{-1}. (In all rate equations that appear in this paper the gas constant, R, has the value 1.987 cal·mol^{-1}·K^{-1}), and we assign a rate constant for the reaction, (R4), a value of $k(R4) \approx 10 \text{x} k(R7)$.

Reaction, (R5),

$$PD \rightarrow D + HCl \qquad \text{(R5)}$$

is a molecular elimination reaction leading to PCDD formation. Rate expressions for the molecular elimination of HCl from alkyl chlorides have been reported [29,46], with pre-exponential factors in the range typically $\approx 10^{13.5\pm0.5}$ and activation energies of typically $E_A \approx 50 \pm 5$ kcal mol^{-1}. Reaction rates for gas phase molecular elimination of HCl from aromatics are not reported in the literature. However, the reaction is not likely to be faster than above, due to geometric requirements on the orientation of the hydrogen and chlorine atoms on the two rings and the strengths of the bonds involved [10,20]. The closest analogue for reaction (R5) which we have been able to find in the literature [47a,b] is the unimolecular elimination of HCl from 1-(1-chloroethly)-2-methylbenzene for which a rate constant of $k = 3.55 \times 10^{13} \exp(-44,830/RT)$ s^{-1} is reported [47a]. We assign the value $k(R5) \approx 10^{14} \exp(-45000/RT)$ s^{-1} to the rate constant for reaction, (R5) in order to bias the mechanism in favor of PCDD formation. In fact, by analogy to other aromatic systems [48,49] there is reason to suspect a substantially higher activation energy as well as possible competition between this molecular elimination channel and other simple unimolecular bond fission reactions. It is also likely that there is a small steric factor to be associated with reaction, (R5) [10].

Reaction (R6),

$$PD + OH \rightarrow D + H_2O \qquad \text{(R6)}$$

is similar to reaction (R2), for which we have previously estimated a bimolecular rate constant of $k(R2) \approx 10^9$ L·mol^{-1}·s^{-1}. Here we assume reaction, R(6), is actually a combination of a rate limiting abstraction reaction

$$PD + OH \rightarrow PD\cdot + H_2O \qquad (R6)'$$

leading to production of a polychlorinated 2-phenoxyphenoxy radical which then rapidly reacts unimolecularly to form a PCDD

$$PD\cdot \rightarrow D \qquad (fast)$$

and ignore the possibility of decomposition, in order to bias the mechanism in favor of PCDD formation. For the same reason, we ignore the addition reaction of OH.

Reaction (R8),

$$P\cdot + OH \rightarrow Pr \qquad (R8)$$

is expected to be faster than reaction (R2), since both reactants are radicals. However, to bias the mechanism in favor of PCDD formation, we will assume the rates are comparable and set k(R8)= k(R2).

Reaction (R9),

$$D \rightarrow Pr \qquad (R9)$$

represents the unimolecular dissociation of a PCDD to form products which will, at the temperatures where reaction (R9) becomes important, subsequently undergo further decomposition. We have previously estimated a rate constant of $k(R9) \approx 10^{15.5} \exp(-80000/RT)\ s^{-1}$ [10] for this reaction.

Reaction (R10),

$$OH + D \rightarrow Pr \qquad (R10)$$

is the bimolecular reaction of a PCDD with a hydroxyl radical. We have previously estimated a value $k(R10) \approx 10^9\ L\cdot mol^{-1}\cdot s^{-1}$ for this reaction [10,11]. We bias the mechanism in favor of PCDD accumulation by reducing this value to $k(R10) \approx 10^8\ L\cdot mol^{-1}\cdot s^{-1}$.

Reaction (R11),

$$O_2 + P\cdot \rightarrow Pr \qquad (R11)$$

is the bimolecular reaction of a polychlorinated phenoxy radical with molecular oxygen. The reaction of the unsubstituted phenoxy radical with molecular oxygen has been estimated to have a rate constant of $\approx 10^8\ L\cdot mol^{-1}\cdot s^{-1}$ [48-51], and we assign this value here.

Reaction (R12),

$$R + OH \rightarrow R\cdot + H_2O \qquad (R12)$$

is expected to be slower in general than reaction (R8). However, to bias the mechanism in favor of PCDD formation, we will set $k(R12) \approx 10^9$ $L \cdot mol^{-1} \cdot s^{-1}$, since the availability of the species, R, will decrease the concentration of P· through reaction (R7). The reverse of reaction (R12), is neglected since in combustion typical of incineration, the radical R·, resulting from hydrogen atom abstraction is highly labile and can react further with molecular oxygen, other fuel molecules and hydroxyl radicals, which will be present at substantially higher concentrations than the phenoxy radical [8-10,30].

Reaction (R13),

$$R \rightarrow Pr \qquad (R13)$$

like reaction (R12), actually represents a broad spectrum of reactions, and we assign a typical value of $k(R13)$ 10^{16} $\exp(-90000/RT)$ s^{-1} [29,46]. These reactions are strongly temperature dependent, and will tend to become important at temperatures at which PCDD destruction, as opposed to formation is already strongly favored.

Computer Simulation

The mechanism, as given in Table I has been used to study the possibility of PCDD formation under typical incinerator combustion conditions through computer simulation via a standard Gear type [52] ordinary differential equation system solver. Various initial conditions as described below were tested. We considered a typical trichlorinated phenol, although this choice is arbitrary in view of the generalities of the mechanism. Initial mole fractions of fuel reactant and oxygen are assigned based upon assumption of stoichiometric combustion (equivalence ratio equal to one) and conversion to carbon dioxide, water and HCl as major products. Atmospheric pressure was assumed and reaction at a range of temperatures from 500 K to 1500 K was investigated. Four cases (i-iv) were examined, for which initial mole fractions are as given in table 2. In all cases, the concentration of hydroxyl radical was defined through the assumption of local equilibrium to be $(OH)_{EQ} \approx 10^{-1.7}$ $\exp(-35000/RT)$ $mol \cdot L^{-1}$ [10,30].

Case (i) is used as a base against which to test the role of molecular oxygen and auxilliary hydrocarbon fuel in the destruction of polychlorinated phenols and in the possible formation of PCDDs. In actual stoichiometric or fuel lean combustion, there are (except in the case of mixing inhomogeneities between fuel and air) considerable molecular oxygen available up to the point of substantial fuel conversion. Therefore, this case is actually worse than the true situation and probably greatly exaggerates gas phase PCDD formation beyond what is realistically to be expected in ordinary combustion in the absence of significant mixing inhomogeneities between fuel and air. It is also not representative of a pyrolysis process, where $[OH] \ll [OH]_{EQ}$. In fact, for pyrolysis the mechanism would have to be developed differently, with inclusion of unimolecular initiation reactions such as reaction, (R1), and exclusion of emphasis on reactions involving hydroxyl radical attack. Note, however, that in the gas phase these reactions are likely to be characterized by large activation energies. Thus gas phase pyrolysis may not necessarily be expected to produce substantial amounts of PCDDs, as initiation reactions may have rate constants comparable to those for decomposition of PCDDs etc. In addition, it is possible that polymerization reactions would have to be included as part of the pyrolysis process [40,41]. With great care, since the mechanism is biased in favor of PCDD formation, this case may possibly be regarded as suggestive of the situation in which an unburned fuel pocket, due to mixing inhomogeneities, passes into a post combustion zone where oxygen has already been depleted, but the [OH] radical concentration still tracks the local temperature in the incinerator. However, to determine fully the importance of this case one would have to analyze carefully the statistical character of variations of fuel/air inhomogeneities throughout a combustor and in addition develop refined estimates of the rate constants to eliminate the bias. In the case of a well designed incinerator we suspect the importance of fuel/air inhomogeneities is probably small relative to the bulk combustion process. This case in which the fuel is a pure phenol in no way corresponds to municipal incineration where such a chlorinated compound would only be present as a trace substituent in the input feed stream and not as a major component. In any event, note that in fact, if the phenol were present as a nearly pure compound in a waste stream, it would be most likely recovered for further use rather than destroyed thermally.

Case (ii) is more suggestive of combustion of a chlorophenol under hazardous waste incinerator conditions. Normally, most incinerators are run under stoichiometric or excess air conditions. However, to bias the mechanism in favor of PCDD formation we have adjusted the initial mole fraction of molecular oxygen to a level of about 60 percent of its value in stoichiometric combustion. This has the effect of de-emphasizing the rate of loss of the phenoxy radical, P·, via reaction R11.

Case (iii) corresponds to a fuel rich pocket in a post combustion zone environment in the combustion of a mixture of a phenol and an excess of an auxiliary hydrocarbon fuel. This case is intermediate between combustion in a liquid hazardous waste incinerator where the percent of chloro-organic could be higher and the case of municipal incineration where the chloro-organic content would be lower. Again, molecular oxygen is treated as though it were unavailable.

Case (iv) is similar to case (iii) but has molecular oxygen present during the combustion stage. Case (iv) is to be compared to case (iii) as case (ii) is to case (i).

Discussion

The results of modeling these four cases for combustion during an elapsed time period of one second, which is a residence time typical of incineration are presented in table 3. The symbols P, P·, D, R and PD used in table 3 are defined in figure 1. Below, the results are analyzed. Concentrations for all four cases were computed for a wide range of reaction times other than t = 1 second but are not presented here to save page space.

Under the conditions of case (i) - i.e. post-combustion mixing and reaction of unburned phenol with hydroxyl radicals, some substantial PCDD formation is indicated at intermediate temperatures. This is the only case where that is true. However, this case is not realistic. It assumes the entire initial mole fraction of phenol makes it into the post combustion zone of an incinerator. This is not likely to happen. In fact under normal operating conditions in a well designed incinerator, only a very small amount of unburned fuel would be likely to enter the combustion zone. Therefore, realistically, these mole fractions of PCDD produced under case (i) would have to be weighted by the fraction of fuel which actually makes it to the post combustion zone. On the basis of such a weighting process, one would expect a much lower PCDD formation than indicated in case (i).

In all the other cases it is quite clear that PCDD production is very low. The use of auxiliary fuel, stoichiometric or excess air and high temperatures (all of which are common operating conditions) promote phenol destruction to products other than PCDDs. At flame temperatures, gas phase PCDD formation would be below detection limits. Note also from Table III that in all cases the level of 2-phenoxyphenol formation is predicted by the mechanism which has been utilized, to be much lower than PCDD formation. In part this may possibly explain why phenoxyphenols are not commonly reported as products of combustion.

In actual practice, it is found that PCDD emissions sometimes exceed the levels predicted by the above results. This requires consideration in some detail as to the nature of these circumstances. Some additional possibilities may be:

a) PCDDs were originally present in the input feed streams and survive thermal destruction in significant amounts.

b) Due to mixing inhomogeneities some unburned chloroorganics survive the main combustion environment and make it into the post-combustion zone.

c) Temperature fluctuations (thermal transients) result in incomplete thermal stressing due to gas entrapment in cold pockets, promoting PCDD production at above ambient but below flame temperature conditions.

d) Molecules other than polychlorinated phenols are being converted to PCDDs in the gas phase.

e) Inorganic chlorine sources in municipal waste input feed streams lead to chlorination of organics and ultimate formation of PCDDs in the gas phase.

f) Non-gas phase, or a combination of gas and non-gas phase reactions are contributing to the production of PCDDs during the combustion process.

With regard to (a), it has been stated that at least for municipal waste streams, PCDDs are not initially present in input feedstreams in significant amounts [5], to the extent that would be required to account for observed levels of emissions. In the case of hazardous waste incineration streams, the situation would depend on the feedstock. By way of a hypothetical example, note that if it were the case that a municipal waste stream contained 1 part per thousand of polychlorinated phenols which in turn contained 100 ppm of a PCDD impurity, then the expected PCDD level in the effluent stream (gas plus fly ash combined) would be on the order of tens of ppb if the PCDD destruction efficiency were zero (due to dilution) and would readily fall to a few parts per trillion once the destruction efficiency exceeds 99 percent for the PCDDs. We have previously described an estimation procedure for calculating the expected destruction efficiencies if homogeneous mixing is developed in the gas phase of an incinerator [10,11]. This procedure was applied to the case of PCDD destruction. We could conclude from these estimates that the gas phase thermal destruction efficiency for PCDDs is extremely high at flame temperatures typically achieved in an incinerator [10,11].

With regard to (b), further investigation is warranted as there is not much data presently available about statistically representative temporal or spatial frequencies of unburned fuel pockets of varying fuel/air composition in practical incinerators. Mixing inhomogeneities may develop for various reasons, e.g., poor atomization may sometimes be a problem in liquid hazardous waste incinerators. Samuelsen [53] has discussed the formation of eddies or pockets of varying fuel air mixtures in non-premixed flames. Breen [54] has estimated that eddy lifetimes may range anywhere from 10 to 50 milliseconds. Whether or not these eddies will ignite depends significantly upon the fuel/air ratio in an eddy and upon the extent to which an eddy may mix together with other eddies [53]. Appelton and Heywood [55] have discussed how inhomogeneities due to eddies or pockets of varying fuel/air mixtures may affect pollutant formation in continuous flow combustors burning atomized liquid fuels.

In addition, in the case of liquid injection, peculiarities of the liquid mixture being injected may sometimes present problems. Wood and others [56] have demonstrated that during the combustion of a multi-component fuel drop, the composition of the drop and its surrounding vapor change by a process of simple batch distillation. The inference here is that one must sometimes be careful as to which fuels are to be mixed together if fuel properties are such that substantial distillation may be likely to occur. As an example, consider the injection of a mixture consisting of small amounts of chloroform and chlorophenol diluted in an auxilliary hydrocarbon fuel such as n-octane. To begin with, if atomization and/or mixing are poor, the maximum temperature will occur, not at the stoichiometric equivalence point, but at a somewhat lower equivalence ratio (leaner fuel mix than theoretical stoichiometric composition) corresponding to introduction of a substantial amount of excess air [57]. At this maximum temperature point, the mixture will be efficiently thermally decomposed. On movement into the fuel lean and fuel rich sides of this maximum temperature point, temperatures may be increasingly substantially lower and destruction efficiencies may be component specific. In apparent contradiction to expectations based upon a kinetic scale of incinerability [30], one would observe in some off maximum temperature circumstances, due to the batch distillation process, that much more chloroform than chlorophenol could persist through the combustion zone. This is because the selective evaporation of chloroform into the vapor phase rapidly enriches the vapor phase in this component as the droplet begins to evaporate [58]. Depending on the amount of enrichment this can significantly reduce the extent of reaction in the chloroform enriched vapor phase due to the flame inhibiting characteristics of the resulting mixture [59,60]. If the combustion zone is small, subsequent fluid hydro dynamic processes may remove some of this self inhibiting mixture from the region of the combustion zone before more substantial mixing and enhanced combustion can occur. At the same time, the liquid droplet is becoming enriched in chlorophenol and auxilliary hydrocarbon fuel (increasing mole fraction) by the distillation process. This mixture may have less flame inhibiting character (due to chloroform removal) and as such will subsequently burn more completely on evaporation. Thus more chlorophenol than chloroform is destroyed in these circumstances. It may be the case that as the chlorophenol is mostly contained in a droplet which is burning at or near its boiling point [61], some conversion to secondary products of formation may occur within the droplet prior to complete evaporation. However, this in itself (and similarly for the case of secondary product formation due to pyrolysis reactions which might occur during the short period of warmup of the escaping vapor to its ignition point [62]) would not necessarily create a hazardous secondary product emission problem if the chlorophenol enriched droplet subsequently totally evaporates within the high temperature combustion zone and providing the off-maximum temperature is still substantially high enough to thermally decompose the resulting gas phase mixture. Similar arguments would apply to the small amounts of chlorophenol lost to the chloroform enriched vapor phase. A complication could arise if flame inhibition occurs to such a substantial extent that it results in flame extinguishment in the region of the chlorophenol enriched drops. This problem could possibly be solved by allowing for a large enough combustion zone such that the droplet could subsequently be re-ignited. In most cases, some approaches to these problems would be to improve atomization, improve mixing, adjust the initial fuel mixture composition to avoid undesirable distillations, provide for a high temperature combustion zone transit time which significantly exceeds the droplet burnout and mixing times, or to employ afterburners (staged combustion).

In any event, predictions of incinerability based upon chemical kinetics [30] are still possible. The problem of the apparent breakdown of a kinetic scale of incinerability is solved by recognizing that the incinerability scale is designed to be applied to homogeneous gas phase mixtures. Thus, once a distillation process occurs the kinetic scale of incinerability must be applied separately to enriched and depleted vapor mixtures and their local environment temperatures. In this case a weighting must be employed to account for these physical mass transfer effects resulting from the distillation process.

It is possible to design experiments for measuring directly fast transient fuel burning fluctuations [63,64], but these methods have not been commonly applied to the process of incineration. Note that if in fact mixing inhomogeneities are a problem, it is not a problem without possible practical solution for reasons mentioned previously.

The possibility (c), is to an extent, related to the degree of mixing, although other parameters are also operative in controlling thermal fluctuations [65-67]. Detection of fast (100 Hz and higher) thermal fluctuations at a point in space in turbocombustors has been made optically [63] and via physical measurement with fast time constant thermocouples [68-70]. Application of optical detection to an incinerator environment will require correction for substantial particulate entrainment in the flow stream. The application of fast time constant thermal measuring devices will require innovative technology such as R. R. Dils new high temperature optical fiber thermometer [71] to avoid large error measurements, since at flow speeds and temperatures typical of an incinerator, convective transport is greatly diminished relative to the situation in a turbocombustor [68-71]. Under incinerator conditions of low flow rates, thermocouple fast transient temperature measurements are substantially based upon radiative transport, and this dependence is the source of the large errors in these thermal measurements when thermal fluctuations are rapid. Numerical simulations of scales of incinerability or formation in the presence of temperature fluctuations are possible [10,11,30,65-67]. It is important to stress that in numerical simulations of destruction or formation of toxics in non ideally mixed reactive flows with temperature fluctuations, one must as a minimum, account for not only the effects of unimolecular but also of bimolecular processes such as those involving hydroxyl radicals [10,11]. If this is not done, results can be misleading. The extent to which a typical thermal destruction process as characterized by the rate constant expression

$$k_{\text{destruction}} = k_{\text{biomolecular}} [\text{OH}] + k_{\text{unimolecular}}$$

becomes dominated by the unimolecular character may possibly provide useful information about deviations from the ideal case of well mixed fuel/air combustion at flame temperatures. Another important question for case (c) that will have to be addressed is the question as to what extent or not unburned or partially combusted fuel trapped in a relatively cool pocket can be easily transported to the post combustion zone where PCDD formation might possibly take place. While it is known that transport of unburned or partially combusted fuel does occur in some specific instances, for example in a diffusion flame [53-55], a detailed and quantitative assessment of this problem in practical incinerators has not yet been developed. More work needs to be done in this respect, since at least in the case of turbopropulsion, thermal fluctuations can be enormous [68] and fluctuations in turbulent flames in general have been known sometimes to be substantial [53-55,67,71]. We suspect based on observed combustion efficiencies that the statistical probability for transport of unburned fuel in a cold pocket to the post combustion zone is probably low in a well designed incinerator [10].

The possibility (d), that molecules other than polycholorinated phenols lead to gas phase formation of PCDDs under typical incinerator conditions is amenable to the same type of numerical analysis as we have presented in this paper. It is reasonable to expect that the fewer the features a precursor molecule has in common with PCDDs or PCDFs (e.g. aromatic character chlorine or hydroxyl functional groups), the more complex the mechanism one would have to propose for PCDD or PCDF formation. Under these circumstances, at high temperatures, there will probably be more competitive destruction pathways (vs. formation pathways) than in the mechanism we have proposed for PCDD formation from polychlorinated phenols (or polychlorinated 2-phenoxyphenols). Thus, the probability for formation of PCDDs or PCDFs would be expected to decrease under these circumstances. We plan to investigate this further. As mentioned previously, we feel there have been no experiments made to date which unambiguously demonstrate that gas phase formation of PCDDs and PCDFs occurs under typical combustion conditions. We do, however, feel confident that such experiments can be designed and used to test for non gas phase and inhomogeneous mixing effects [8,9,63-71].

The possibility, (e), that of de novo synthesis from inorganic sources of chlorine in the gas phase has not been extensively examined [1,2]. We have investigated briefly the presence of $FeCl_2$, $FeCl_3$ and NaCl in the gas phase through numerical equilibrium modeling under conditions typical of incineration, for example, as outlined in this paper. This modeling indicates that in incineration, temperatures in excess of 1000 K are required for low levels of NaCl to build up in the gas phase and that temperatures in excess of about 1200 K are required for low levels of iron chlorides to develop in the gas phase. Equilibrium conditions at lower temperatures overwhelmingly favor distribution of these metals among non gas phase species.

The quantitative reactivity of NaCl or iron chlorides as a source of chlorine for gas phase chlorination of organics at high temperatures has not been reported. In addition the time required for these inorganic chloride species to develop to equilibrium concentrations is not reported under typical incinerator combustion conditions. In the event that aluminum recycling is not practiced, aluminum chlorides would also have to be considered in a similar manner. Heavy metal chlorides, e.g. $ZnCl_2$, $CdCl_2$ and $PbCl_2$ are much more volatile at these temperatures [72], but except for fairly specific waste streams the amounts of these metals initially present is usually low.

The above discussion implies that even if these materials are present and reactive in the gas phase at incinerator conditions, there are not likely to be any simple mechanisms in which through only a few steps, the production of PCDDs would occur to any significant extent. This is because the bimolecular rates associated with the reaction steps of any proposed mechanism would be low as a consequence of the low gas phase concentrations of these species at incinerator operating temperatures. As seen from our modeling of polychlorinated phenol combustion, at high temperatures PCDD formation involving multistep processes consisting of several reaction steps where reactant concentrations are low to begin with cannot easily compete with other routes which lead to destruction during the combustion process. For these reasons we strongly suspect *de novo* synthesis from inorganic precursors is unimportant in the gas phase. This discussion does not imply, however, that *de novo* synthesis from inorganic sources of chlorine via non gas phase processes is to be discounted. Quite the contrary, multiphase reactions involving inorganic chlorides have been reported, including those which produce HCl and Cl_2 from metal chlorides [73] and those which result in the production of PCDDs [74] and other chlorinated organics [75].

The last and most intriguing possibility, (f), is the assumption that non gas phase or a combination of gas and non gas phase reactions may be contributing to the production of PCDDs during the combustion process. We have previously alluded in this paper to the extensive literature which reports the enhanced reaction sensitivity of organic species to the presence of reactive surfaces. Fly ash itself is principally a mixture of silica and metal oxides [10] and should have many reactive Lewis and Bronsted acid and base sites which could presumably promote reactions [23-25] at temperatures considerably below those at which the previously discussed destruction processes dominate. In fact, chloro-organics formed from reactions in the presence of chlorine and fly ash have recently been reported [21]. We have also indicated that there is other research which appears to suggest oxygenation of chloro-organics to form PCDFs may be due to surface reactions [10]. One must also consider the work of Nestrick and co-workers [27] in synthesizing PCDDs from chlorophenates which must be due to surface reactions in view of the low temperatures in which reactions were carried out. The highly polar nature of the metal to oxygen bond in the chlorophenates that were used and the surface reactivity of the silica support they used probably favor ionic reactions on the surface [23-25], possibly involving surface bound hydroxyl groups and other reactive sites. At these temperatures [27] radical reactions in the gas phase cannot compete. Surface reactions and/or reactions inside solids (such as fly ash and other materials) therefore seem to be strong candidates as potential sources for PCDD and PCDF formation. Transport of these compounds into effluent emissions could then possibly be due to insulation inside particles that have not been sufficiently heated to the core. Presumably, vapor emissions of toxics would in part then be associated with particle outgassing in the post combustion zone [10]. In addition, particles, of PCDD emissions with particle size may be informative in understanding the relative importance of the above possibilities although care in interpreting results may have to be exercised if data is taken from units equipped with electrostatic precipitators due to differences in the ease of ionization of particles of varying material composition.

Other complicating effects associated with particle emissions may at times potentially be encountered. For example: With respect to fly ash particle size as a function of distance measured moving away from an incinerator point source, fly ash particle size distributions taken from soil samples (surrounding the incinerator point source) may shift to deposition of particles of smaller sizes onto the soil. This is anticipated from differences in the terminal gravitational settling velocity between particles of different sizes [76,77]. If the smaller particles have been more thermally stressed in the incinerator due to the strong dependence of particle heat up times with particle diameter [10,78], then isomer distribution ratios of PCDDs/octachloro-DD (e.g. heptachloro-DD/octachloro-DD) formed on the fly ash particles should be observed to asymptotically shift towards lower ratios as one moves away from the incinerator point source, i.e., particle size and PCDD/octachloro-DD ratios reflect their thermal history inside the incinerator and should track each other. That the shift should occur in the direction of lower ratios on moving away from the incinerator point source is a reflection of the increasing thermal [30,79] and kinetic [10,11] stability of PCDDs with increasing degree of chlorination, i.e., on the more thermally stressed particles the more kinetically and thermally stable PCDDs should predominate. The asymptotic nature of the shift reflects the fact that below a certain particle size, essentially complete (to the core) thermal heating of all fly ash particles which have been exposed to high temperatures inside the incinerator has occurred. Whether or not this trend could be interpreted to demonstrate that volumetric as opposed to surface formation (or deposits) of PCDDs are occurring in the incinerator requires further analysis, particularly with respect to heat sinking and particle porosity during the lifetime of the fly ash particle's tranversal through the incinerator. This analysis probably applies to municipal waste incineration where there are not likely to be any significant amounts of PCDDs to begin with. In the case of hazardous waste incinerators the analysis may be more complicated depending upon which if any PCDDs are initially present in the input feedstream.

In addition to reactions inside of or on the surfaces of particles, the possibility for liquid phase transformations may have to be considered in some instances. The literature is replete with reports of organic synthesis of PCDDs in various solutions with and without catalysts (see reference [2] and references contained therein). Liquid phase reactions may possibly occur, e.g., in liquid injection hazardous waste incinerators where atomization is poor and droplet evaporation times approach or exceed combustion zone transit times. In these instances it may be worthwhile to investigate alteration of droplet evaporation times, improving atomization, use of afterburners (staging), etc., as mentioned previously.

A further source of precursors may be from compounds entrained in the input combustion air feedstream itself. For example, Junk and co-workers [80-83] have discussed in careful detail the presence of PCBs in combustion air. Therefore, in addition to waste feedstream sources [1-5, 84] additional consideration may have to be given to the history of combustion air as it passes through an incinerator. However, with respect to gas phase formation processes, arguments similar to those presented in this paper probably apply, and PCDD formation from trace organics in input combustion air is therefore probably unimportant at the same conditions and high temperatures that would ordinarily promote PCDD destruction.

Conclusions

Clearly, to more fully understand details of the processes for formation and destruction of toxics such as PCDDs and PCDFs during the process of high temperature combustion, more research is required for reasons and in directions we have indicated above. On the other hand, it is important to recognize that there is no unique thermal or kinetic stability attributable to these compounds [30] that would prohibit their efficient destruction at high temperatures.

We recommend that several research objectives should be set as enumerated below. This listing is not all inclusive but does serve to highlight what we feel are some current research needs with respect to understanding the processes by which PCDDs, PCDFs and similar toxic compounds may be formed and destroyed during practical thermal incineration:

a) Analytical methods should be further developed and applied to quantify types and amounts of specific organic compounds and classes of organic compounds not only as a function of fly ash (or bottom ash, ESP ash, etc.) particle size but also as a function of their distribution on the surface of or inside (volumetric and internal surface due to pores) particles. The same comments should be understood to apply to inorganic species associated with fly ash emissions (or bottom ash, ESP ash, etc.). In addition the distribution of species among the various phases (solid/fly ash, soot; liquid/water aerosol, organic aerosol, gas/evolved gas) needs to be characterized.

b) Efforts should be made to study and understand fast transient phenomena in incinerators, e.g. cold pockets, pre-ignition pyrolysis, mixing inhomogeneities, etc.

c) Much more effort should be directed toward understanding the nature of condensed phase reactions (catalyzed and uncatalyzed), e.g., surface reactions, reactions in solids, etc. This applies not only to incineration but also to land filling.

d) Predictive, reactive flow multidimensional fluid hydrodynamic numerical simulations should be performed to study the dynamic character of the incineration process.

e) Laboratory scale experiments need to be performed as an aid to refining rate constants associated with reaction steps in any proposed mechanisms. These should include both gas phase and condensed phase kinetics. With more refined mechanisms sensitivity analysis should be undertaken. Similarly more thermodynamic data is needed for species such as chlorophenols, PCDDs, PCDFs, etc., which is more reliable than what is currently reported, if predictions of equilibrium isomer distributions are to be made with greater accuracy.

f) Complicating effects, e.g. selective compound distillations, particle size separations, etc., should be examined in more detail.

g) Optical methods should be applied to real time detection of transients species in incinerator environments; especially hydroxyl radical due to its importance in the combustion process. Continuous rather than intermittent (e.g. as with a 10 Hz pulsed laser) measurements would be desirable in order to understand perturbations in concentration measurements due to effects such as vortex shedding.

h) Interferences in analysis, e.g. of organic compounds in fly ash due to naturally occurring particulates, e.g., [85], should be very carefully assessed.

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Table 1. Proposed Biased PCDD Gas Phase Formation Mechanism

#	Reaction Step
R1	P → P· + H
R2	P + OH → P· + H_2O
R3	P· → Pr
R4	P + P· → PD + Cl
R5	PD → D + HCl
R6	PD + OH → D + H_2O
R7	P· + R → P + R
R8	P· + OH → Pr
R9	D → Pr
R10	D + OH → Pr
R11	P· + O_2 → Pr
R12	R + OH → R· + H_2O
R13	R → Pr

Table 2. Initial Mole Fractions[(a)]

	CASE (i)	CASE (ii)	CASE (iii)	CASE (iv)
$X_{02}^{(b)}$	0.	0.1	0.	0.1
X_R	0.	0.	$99X_P$	$99X_P$
X_P	3.16×10^{-2}	3.16×10^{-2}	3.16×10^{-4}	3.16×10^{-4}

(a) $(OH) \approx (OH)_{EQ} \approx 10^{1.7} \exp(35000/RT)$ [30]. Total pressure = one atmosphere (760 torr). Other species, e.g. N_2, H_2O, HCl, Pr, etc., which do not participate as reactants in the mechanism shown in Table I make up the balance of the mole fractions not explicitly detailed in Table II.

(b) In cases (ii) and (iv), the mole fraction of molecular oxygen has been set to a level of about 60 percent of the stoichiometric combustion value as follows from the discussion presented in the body of this paper.

Table 3a. Concentration(a) of species after 1 second: case(i)

T(k)	P	P·	D	R	PD
500	7.70-4	2.31-16	6.58-28	1.00-20	7.10-22
600	6.42-4	2.03-9	2.34-16	1.00-20	2.01-13
700	5.50-4	1.20-7	5.31-11	1.00-20	1.86-10
800	4.79-4	2.41-6	4.21-8	9.95-21	1.83-9
900	4.01-4	1.85-5	1.97-6	9.42-21	3.16-9
1000	2.46-4	1.09-5	7.18-6	1.20-21	1.73-12
1100	4.11-5	6.83-7	1.91-6	1.20-21	1.73-12
1200	6.21-8	4.57-10	3.43-10	2.22-24	8.42-19
1300	9.34-19	4.12-21	5.43-32	1.45-34	1.49-36
1400	5.26-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70
1500	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70

(a) e.g.: The number: 1.53-12 is 1.53 x 10^{-12} moles/liter. The symbols P, P·, D, R and PD are defined in Figure 1.

Table 3b. Concentration of species after 1 second: case(ii)

T(k)	P	P·	D	R	PD
500	7.70-4	2.79-17	7.95-29	1.00-20	8.58-23
600	6.42-4	1.01-14	3.69-21	1.00-20	2.05-18
700	5.50-4	6.80-13	8.43-16	1.00-20	1.85-15
800	4.79-4	1.59-11	5.64-13	9.95-21	1.23-14
900	4.03-4	1.75-10	3.48-11	9.42-21	3.02-14
1000	2.53-4	8.71-10	6.68-10	6.56-21	3.23-14
1100	4.04-5	7.69-10	2.29-9	1.16-21	1.91-15
1200	5.74-8	4.75-12	3.61-12	2.05-24	8.10-21
1300	2.07-18	6.76-22	7.97-33	3.10-34	2.19-37
1400	3.11-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70
1500	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70

Table 3c. Concentration of Species After 1 Second: Case(iii)

T(k)	P	P·	D	R	PD
500	7.70-6	2.31-18	6.58-32	7.63-4	7.10-26
600	6.42-6	2.08-11	2.55-20	6.35-4	2.12-17
700	5.50-6	1.20-9	5.31-15	5.45-4	1.86-14
800	4.79-6	2.45-8	4.26-12	4.74-4	1.86-13
900	4.03-6	2.00-7	2.09-10	3.99-4	3.45-13
1000	2.52-6	1.17-7	7.73-10	2.49-4	4.34-14
1100	4.12-7	6.85-9	1.95-10	4.10-5	1.73-16
1200	6.52-10	4.80-12	3.61-14	7.38-8	9.29-23
1300	9.92-21	4.38-23	2.82-36	4.51-36	7.73-41
1400	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70
1500	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70

Table 3d. Concentration of Species After 1 Second: Case(iv)

T(k)	P	P·	D	R	PD
500	7.70-6	2.79-19	7.93-33	7.63-4	8.57-27
600	6.42-6	1.01-16	3.70-25	6.34-4	2.06-22
700	5.50-6	6.80-15	8.46-20	5.45-4	1.86-19
800	4.79-6	1.59-13	5.64-17	4.74-4	1.23-18
900	4.03-6	1.75-12	3.49-15	3.99-4	3.02-18
1000	2.52-6	8.68-12	6.71-14	2.49-4	3.21-18
1100	4.16-7	7.92-12	2.31-13	4.14-5	2.02-19
1200	6.29-10	5.21-14	3.95-16	7.13-8	9.74-25
1300	9.03-21	2.96-24	1.57-37	4.12-18	4.31-42
1400	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70
1500	<1.00-70	<1.00-70	<1.00-70	<1.00-70	<1.00-70

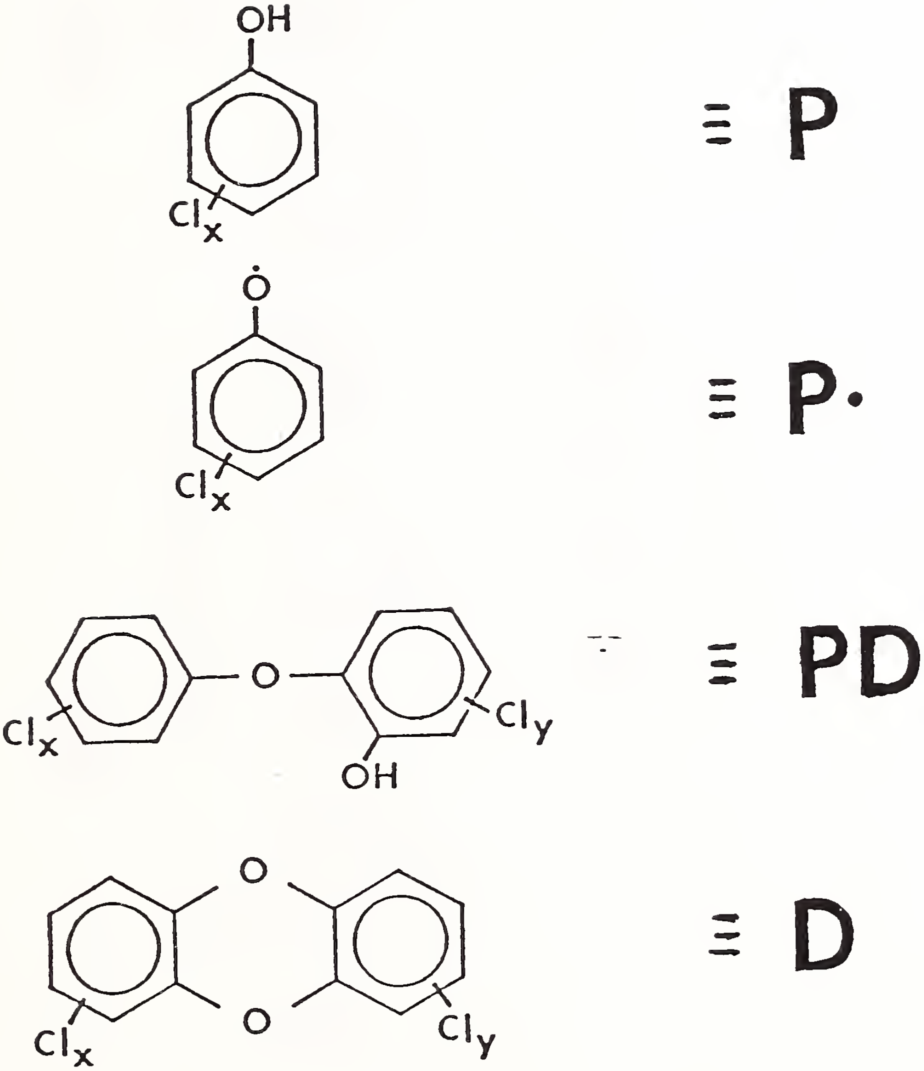
OH
Clx
≡ P
Ȯ
Clx
≡ P·
O
Clx
Cly
OH
≡ PD
O
O
Clx
Cly
≡ D

Figure 1. Species contained in the model mechanism.

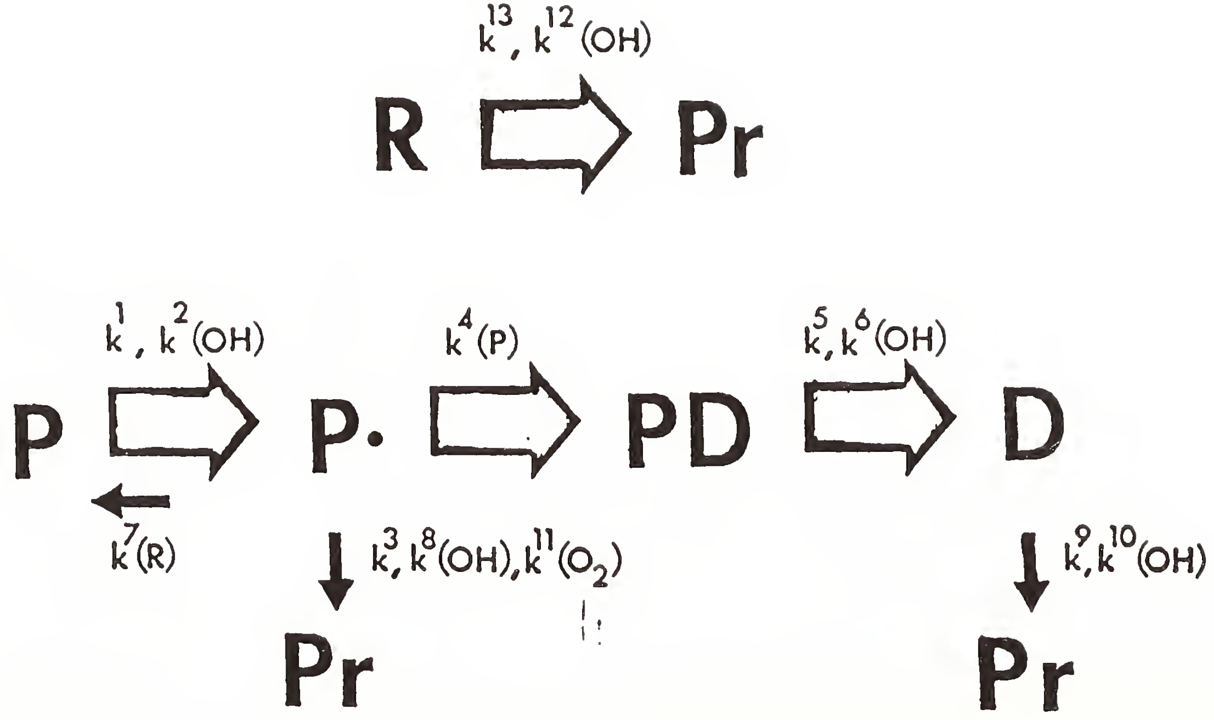
k13, k12(OH)
R
Pr
k1, k2(OH)
k4(P)
k5, k6(OH)
P
P·
PD
D
k7(R)
k3, k8(OH), k11(O2)
k9, k10(OH)
Pr
Pr

Figure 2. Biased mechanism schematic.

APPENDIX IV. NON-CONCRETE USES OF FLY ASH IN CONSTRUCTION MATERIALS

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ABSTRACT

Current and potential non-concrete uses for fly ash in construction materials are identified. Benefits and limitations of fly ash utilization in its applications are described. Fly ash production, and physical and chemical properties are reviewed. Current uses include structural fill, road base, asphalt filler, grout, mine reclamation, aggregate, landfill liner, brick manufacture, and concrete block. Potential applications include use in prefabricated walls and mineral element recovery. The cenosphere fraction of fly ash has potential uses in plastic extenders, foams, coatings, paints, rubber compounds, tapes, sprays, sands, fire proofing, and insulation. Primary use limitations are fly ash compositional variability, transportation costs, and lack of material technical specifications.

Key words: aggregate, brick, building materials, cenospheres, cost effectiveness, fly ash, non-concrete, landfill liner, limitations, pavement, prefabricated walls, specifications, utilization.

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1. INTRODUCTION

Fly ash is the non-volatilized inorganic matter and unburned organic material collected from the exhaust gasses of furnaces which burn pulverized coal. Fly ash can be collected in various antipollution devices, including mechanical cyclones, electrostatic precipitators, baghouses, and/or scrubbers on the stack of the coal combustion unit. Until recently, fly ash had been considered a liability to the operators of coal fired utilities. The Department of Energy (DOE) is studing the use of fly ash as a resource material for use in construction and other industries. As a part of this effort, DOE has asked the Bureau of Standards to investigate non-concrete uses of fly ash in construction materials. This report shows that fly ash is a cost effective component of numerous construction materials including aggregates, landfill liners, brick raw material, and road pavement admixture.

The predominant construction application of fly ash is as a partial replacement for cement in concrete. As this use has been addressed previously (1), this discussion will focus upon construction applications of fly ash other than in concrete. Both currently established and potential construction uses for fly ash will be discussed in this paper.

Approximately 57.5 million tons (52 million tonnes) of fly ash was generated from the combustion of 500 million tons (454 tonnes) of coal in 1979. Only 10 million tons (9 million tonnes) (17.4 percent) of this material was utilized that year. The bulk of the unused fly ash was either disposed of in lagoons and dumps (2) or stored in stockpiles (1). As of

1980, over 300 million tons (272.13 million tonnes) of fly ash were stored in stockpiles. Projected U.S. coal consumption and fly ash generation figures for the late 1980s are 900 and 120 million tons (816 and 132 million tonnes) per year, respectively. Data for 1979 indicate that unused fly ash will reach 90 million tons (82 million tonnes) per year by the early 1990's if this level of increase is maintained (3). Disposal of this unused fly ash is an escalating problem, in terms of both economy and environment.

Energy concerns in recent years have brought about the practice of considering the energy demands in the cost of a project. The use of alternative construction materials, such as those incorporating fly ash, will in some cases require less energy input in their production, handling, and placement than traditional materials (5).

Clearly, there is a need to expand current applications and to explore and implement innovative means of recovery and reuse of this abundant resource. To further this effort, this paper reviews the physical and chemical properties of fly ash (section 2), worldwide fly ash collection and utilization (section 3), current and potential uses for fly ash (section 4), use limitations and research requirements (section 5).

2. PHYSICAL AND CHEMICAL PROPERTIES

The average ash content for all coals is approximately 12.5 percent. Total ash contents by weight of coal utilized range from 3 to 30 percent (4). Of the total ash generated through coal combustion, 15 to 85 percent is fly ash (5). The remaining portions are bottom ash and boiler slag. Variability in the distribution of these ash fractions is due to the type of coal and/or boiler used. For example, cyclone/furnace boilers generate a high proportion of bottom ash (up to 85 percent of total ash), due to high operating temperatures and ash fusion in the furnace (4).

The physical and chemical variability of fly ash, due to its production source (e.g., composition of coal, combustion conditions, fly ash collector utilized), is a significant limitation to its widespread acceptance for use in construction materials (see section 5). The properties of various fly ashes are compared in table 1. Typical fly ash constituents include glassy mineral particles (50-90%), crystalline mineral particles (10-50%), carbon (0-12%), low volatility organic matter (0-1%), and additives used to aid ash collection by electrostatic precipitation (0-0.1%). Fly ash particles are typically tan to gray solid spheres measuring 0.5-100 microns in diameter (6). Inefficient burning processes result in darker particles resulting from excess carbon.

Desirable properties of fly ash useful for construction applications include fineness and pozzolanic qualities (having the property of cementation in the presence of lime and water without itself being a cement) (6).

Table 1. Chemical properties of fly ashes (3)

	Chemical Analysis (percent)								
Type of coal[+]	(S)* SiO_2	(A)* Al_2O_3	(F)* Fe_2O_3	(Total)* S+A+F	Free CaO	CaO	MgO	SO_3	Alkalies as Na_2O	Loss on ignition
Bituminous blend	46.1	19.0	18.6	83.7	2.2	8.2	1.3	1.6	0.72	2.0
Lignite	37.1	11.8	7.3	56.3	0.5	21.8	5.6	2.6	4.23	0.3
Lignite	37.2	15.5	5.6	58.3	0.2	24.3	11.3	0.9	0.07	0.3
Subbituminous	28.8	20.0	4.1	53.0	2.1	32.0	6.4	3.8	0.68	0.2
Subbituminous	51.8	27.2	2.0	81.0	1.9	10.7	2.1	0.7	0.86	1.2
Lignite	31.1	17.1	7.9	56.1	0.0	13.3	8.1	3.3	1.35	1.1

* S = SiO_2; A = Al_2O_3; F = Fe_2O_3

[+] Representative samples of bituminous, lignite, and subbituminious coal

3. OVERVIEW OF FLY ASH COLLECTION AND UTILIZATION

Six and one-half million tons (5.9 million tonnes) (13.3 percent) of the fly ash collected in the U.S. in 1980 was used rather than discarded. This reversed a trend in which fly ash utilization climbed from 7.9% in 1966 to over 17% in 1979 (5). The National Ash Association attributed the 1980 ash utilization decrease to the economic downturn (7). A decrease in the amount of fly ash generated in 1980 reflects a utility industry trend to utilize low ash producing coals in order to increase the reliability of generating units (7). Table 2 summarizes fly ash collection and utilization in 1980 and compares this data with previous years. The table indicates that cement and concrete products comprise the greatest use of fly ash in the U.S. Other significant uses include structural fills, road base, filler in asphalt, grouting, and coal mine reclamation.

Several nations currently use fly ash to a far greater extent than the U.S. (1). Poland, uses 37% of the 18 million tons (16.3 million tonnes) of fly ash it generates for fill material, cement replacement, and aerated concrete blocks. Other leaders in fly ash utilization include England (39% utilization), West Germany (23%), France (42%), Canada (27%), Scotland (30%), and Japan (23%).

4. IDENTIFIED USES

4.1 CURRENT USE

The predominate construction application for fly ash is in the manufacture

TABLE 2a. 1980 Fly Ash Production and Utilization in the United States (5)

	Million Tons	(tonnes)
1. Total Ash Produced	48.31	(43.8)
2. Ash Utilized	6.42	(5.82)
A. Commercial Utilization		
1. Cement & concrete products	2.67	(2.42)
2. Structural fills	0.37	(0.34)
3. Road base	0.13	(0.12)
4. Filler in asphalt mix	0.09	(0.08)
5. Snow & ice control, blasting grit, roofing granules	-0-	
6. Grouting	0.36	(0.33)
7. Coal mining application	0.12	(0.11)
8. Miscellaneous	0.39	(0.35)
Total Commercial Utilization	4.13	(3.75)
B. Ash Used Internally		
1. Structural fills	0.63	(0.57)
2. Road base	0.15	(0.13)
3. Miscellaneous	0.27	(0.24)
Total Ash Used Internally	1.05	(0.95)
C. Ash Removed from Plant Sites at no Cost to Utility	0.07	(0.06)

TABLE 2b. United States Fly Ash Utilization Trends from 1966-1980 (million short tons*) (5)

	1966	1976	1977	1978	1979	1980
Fly Ash Produced	17.1	42.8	48.5	48.3	57.5	48.31
Fly Ash Utilized	1.4	5.7	6.3	8.4	10.0	6.42
% of Fly Ash Utilized	7.9	13.3	13.0	17.4	17.4	13.3

*1 short ton = 0.907 tonnes

of concrete. Other fly ash applications either take advantage of its pozzolanic properties and/or use it as a fill material. Pozzolanic applications include uses as an aggregate, landfill intermediate liner, brick raw material, and paving admixture. Fill related uses include applications as structural and construction related backfills and embankments. Ten of the largest worldwide construction applications for coal ash in 1977 are shown in Table 3. Current non-concrete construction applications of fly ash are detailed in the following.

4.1.1 Aggregate for the Stabilization of Highway Subgrades

A highway subgrades is the surface base of earthen material which is leveled off to receive a road foundation. Fly ash has been used throughout the U.S. as a stabilizer of poor subgrades during road construction since 1950 (5). Soil stabilization uses have been successfully field tested at projects in Kansas City, South Dakota, West Virginia, and other sites (4,7,9). To improve subgrades, fly ashes are normally used to act as either pozzolans or fillers to reduce air voids in naturally occurring or blended aggregate systems. In fine grade soils, use of fly ash as a filler is not suitable since the particle size of fly ash would be larger than the voids in fine soils. But fly ash is of value in fine grade soils as a pozzolan. Many clays are themselves pozzolanic in nature and therefore have no need for additional pozzolanic stabilization. Therefore, the Federal Highway Administration considers silts as the most suitable soil type for stabilization with fly ash-lime or fly ash-cement mixtures (9). Field tests by Kansas City Power and Light (6) showed that addition of 15-20 percent fly ash could be used to improve the properties of highly plastic (easily deformed) clay subgrades with excellent results. Fly ash

TABLE 3. World Use of Coal Ash in 1977 (3)

Use	10^6 tonnes/yr[a]	Leading Users[b]
Fill material	5.8	England, USA, Canada
Cement replacement	5.6	USA, England, E. Germany
Addition to cement	4.1	France, Spain, W. Germany Poland, Austria, USA
Road stabilizer	3.1	Poland, England, USA
Aerated concrete blocks	1.8	Poland, England
Blast grit and roofing	1.6	USA, W. Germany
Asphalt filler	1.2	W. Germany, USA
Pozzolanic material	1.0	USA, France
Lightweight aggregate	0.8	England, USA, E. Germany
Bricks and ceramics	0.6	W. Germany, Ukraine, E. Germany
Other	9.6	USA, Poland, E. Germany W. Germany
Total	35.2[c]	

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[a] 1 tonne = 1000 kg = 1.1024 short tons

[b] In order of decreasing quantity used.

[c] Total ash production is 278 x 10^6 tonnes/yr, 12.7% of world fly ash production.

improved clays at the test site had increased strength and decreased plasticity. Comparing the costs of various road paving operations, Table 4 indicates that lime-fly ash aggregate base construction is cost competitive with cenemt and asphalt treated highway bases (10).

Table 4. Costs of Common Road Pavement Construction Operations (1978) (10)

	Costs \$/sq yd/in. (\$/0.836 m^2/2.54 cm)	
Construction Operation	Average	Range
Crushed Stone Base	0.50	0.30-0.60
Gravel Base	0.40	0.20-0.60
Lime Stabilized Subgrade	0.25	0.15-0.35
Cement Stabilized Subgrade	0.30	0.20-0.40
Cement Treated Base	0.80	0.60-1.10
Asphalt Treated Base	0.80	0.60-1.00
Lime-Fly ash Aggregate Base	0.70	0.60-0.80
Chip Seal	0.35	0.20-0.45
Asphalt Concrete	1.00	0.70-1.20
Portland Cement Concrete	1.40	1.00-2.00

4.1.2 Intermediate Cover in Sanitary Landfills

Fly ash has been used successfully as an intermediate cover in sanitary landfills (11). Projects reporting success in using fly ash as an intermediate cover include landfills at the Orange and Rockland Utilities, the Columbus, Ohio Municipal Light Company, and the City of Fairbanks, Alaska. West Virginia University has conducted additional research in this area regarding the use of injected ash as a stabilizing agent in landfills.

4.1.3 Aggregate and Pozzolan for Road and Airport Pavement Base Material

According to the National Ash Association (11), a 30 inch (76.2 cm) thick lime-cement-fly ash airport runway base has a load performance equivalent to 16 inches (40.6 cm) of portland cement concrete or 60 inches (152.4 cm) of aggregate base asphaltic concrete. The New York Port Authority is utilizing over a quarter million tons of this fly ash mixture for various paving projects at the Newark and Kennedy airports. Cost estimates for this alternative construction material were reported to result in savings of up to 60 percent compared to portland cement and aggregate base asphaltic concrete (11).

Fly ash-lime sulfate sludge compositions are reported to produce a useful paving and stabilization material having strength properties resembling concrete while realizing substantial energy savings (10, 12). Fly ash, as a component of highway base course materials, has been reported to perform satisfactorily in the areas of soundness, abrasion, and percent of fines (13). Initial gradation deficiencies that were experienced in the use of fly ash in highway base course were overcome by the addition of other aggregates such as gravel, limestone, or blast furnace slag.

4.1.4 Construction of Structural Landfills and Backfills

Compacted fly ash embankments are used extensively in Great Britain where its characteristic light weight makes it attractive when embankments are constructed over poor ground (13). Low weight, good shear strength, high load bearing characteristics, and high cohesion give fly ash a better slip circle safety than other embankment materials such as clay or stone. Fly ash has been used as a structural fill in France, West Germany, Finland, Poland, and the USSR. Reported uses of fly ash as a structural fill in the U.S. include a housing project in West Virginia, approach embankments to a railroad overpass in Minnesota, and an embankment for a 1.5 mile (2.41 kilometer) section of the Amstutz Expressway in Illinois (3).

4.1.5 Raw Material to Manufacture Light Aggregate

Fly ash pelletizing and sintering techniques for the manufacture of lightweight aggregate have proven successful. Useful characteristics of the aggregate include pozzolanic properties and resistance to freezing and thawing (15). In the United Kingdom, "LYTAG," a lightweight fly ash aggregate product, has been used in the manufacture of block and concrete (16).

4.1.6 Aggregate in Cold Mixed Asphalt

The State of Texas recently completed a 10,000 mile (16,090 kilometer) highway project which used a non-skid asphaltic material containing lightweight fly ash aggregate. An asphalt mixture (Gussaphalt) containing fly ash which had been used in Germany was recently tested on the Pennsylvania Turnpike near Bedford (16).

4.1.7 Raw Material for Brick Manufacture

Fly ash brick was first manufactured in the U.S. on a trial basis in 1949 (10). It has been found to have favorable characteristics compared to clay brick, while its manufacture utilizes 20-50 percent less energy than that of clay brick (18). Energy savings are attained due to the different manufacturing processing methods of the two brick types. Clay must be mined and crushed, while fly ash brick is composed of fly ash and bottom slag without any preprocessing before use. Clay must be crushed and extrusion formed with 20-25 percent added water, while fly ash needs no crushing and only 6-8% added water for dry pressing. Clay brick must be kiln fired for 30 to 40 hours while fly ash brick requires only 3 to 18 hour firing. Finally, transportation savings can be realized with fly ash brick due to its 10 to 20 percent weight advantage. Cost data for this material has not been reported.

A large commercial fly ash brick manufacturing facility began operations in Canada in the early 1970's (11). This facility initially produced over 6 million bricks composed of 3 parts fly ash to 1 part slag and a small amount of sodium silicate. The brick produced are light, strong, and amenable to coloring. As shown in tables 5a and 5b, fly ash brick is more porous and absorbs slightly more water absorbant than clay brick. Fly ash brick, however, has a significantly greater compressive strength than its clay counterpart.

Fly ash thermal insulation bricks, manufactured in combination with lime, gypsum, and aluminum powder, are reported to cost only about 50 percent that of conventional diatomite and mica insulation bricks. In India, these bricks have been used successfully up to a hot face temperature of 800° C (19).

According to the Resource Recovery and Utilization Technical Committee and Envirosphere Company, the best market for fly ash utilization in the immediate future is in highway construction, due to price increases in asphalt and portland cement (4).

Other current non-concrete uses for fly ash include (3,11,17,19-22):

o Filler for paint, putty, and wall plaster

Table 5a. Properties of Fly Ash Brick (17)

	Northern West Virginia Fly Ash Brick	Southern West Virginia Fly Ash Brick	Western Pennsylvania Fly Ash Brick
%Abs. 24 Hr. Soak	5.58	6.04	6.50
%Abs. 5 Hr. Boil	8.03	7.83	9.48
Saturation Coefficient	0.71	0.77	0.68
Apparent Porosity,%	17.09	16.53	19.20
Bulk Density, Kg/m^3	2124	2108.5	2024
% Shrinkage	7.4	8.6	9.8
Unfired Compressive Strength, Kg/m^2	0.557	0.170	0.518
Fired Compressive Strength, Kg/m^2	2.31	2.35	2.11
Suction, Gms. H_2O/30 Sq. In./Min.	37	37	47
ASTM Grade	SW	SW	SW

Table 5b. Properties of Clay Brick (17)

	Ohio Clay Brick	Pennsylvania Clay Brick	West Virginia Clay Brick
% Abs. 24 Hr. Soak	4.54	3.39	2.70
% Abs. 5 Hr. Boil	5.32	3.74	4.83
Saturation Coefficient	0.85	0.90	0.56
Apparent Porosity,%	12.51	8.57	10.84
Bulk Density, Kg/m^3	2349	2289	2245
% Shrinkage	5.5	7.0	8.2
Unfired Compressive Strength, Kg/m^2	0.207	0.249	1.291
Fired Compressive Strength, Kg/m^2	1.637+	2.133	1.555
Suction, Gms. H_2O/30 Sq. In./Min.	7	6	36
ASTM Grade	SW	SW	SW

- Lightweight aggregate block
- Ingredient in the manufacture of roofing felt
- Ingredient in bituminous stabilized bases for highways
- Revegetation of surface mine spoil sites and coal refuse piles
- Ingredient in lime-cement-fly ash composite in the manufacture of paving mix
- Ingredient in grout
- Pipe mix (as a replacement for cement)
- Mineral filler in asphaltic concrete
- Correction and deterrence of underground subsidence

4.2 Potential Uses

Although the use of fly ash has increased over the years, as discussed in Section III, there is clearly potential for considerable expansion - not only in the many already established markets for fly ash applications, but in innovative uses. These potential uses for fly ash are discussed in the following.

4.2.1 Cenospheres

Cenospheres, or "floaters," are minute silicate glass spheres, constituting up to 5 percent by weight (20 percent by volume) of fly ash produced. Among their potentially useful physical qualities are included excellent compressive strength, chemical inertness, high temperature resistance, and low thermal conductivity. It has been predicted that properly graded cenospheres can could command a price approaching $500 per ton (0.907 tonne) (5,19). Cenosphere applications currently under investigation include:

- plastic extenders
- aluminum
- paints
- tapes
- sands
- insulation
- foams
- coatings
- rubber compounds
- sprays
- fire proofing

4.2.2 Sanitary Landfill Liner

Fly ash may be used to improve the properties of the soils used to line sanitary landfills. Tennessee Valley Authority studies indicate that a 1:1 or a 1:3 mixture of soil to dry fly ash reduced soil moisture absorption rates to "slow." A 1:1 mixture of soil to wet fly ash produced similar results (4).

4.2.3 Raw Material for Making Mineral Wool Insulation

The Coal Research Bureau at West Virginia University has shown that it is both technically and economically possible to produce mineral wool insulation from fly ash, limestone modified fly ash, and other coal ashes (17). The insulation produced has a smaller fiber diameter than commercial mineral wool but its insulating properties are reported to be superior to its commercial counterpart. Advantages of the use of fly ash mineral wool include:

- elimination of mining costs required for acquisition of wool rock,
- reduced raw material preparation,
- elimination of the need for fluxing agents,
- availability of raw materials near most major markets,
- potential for reduced piping maintenance due to anti-corrosion characteristics of fly ash mineral wool,
- and improved insulating and heat duty characteristics due to its high silica and alumina content. Disadvantages of fly ash mineral wool development include the requirement for reverberatory furnaces for which melting must take place on a batch or semi-batch basis (rather than continuous cupolas used in current commercial processes), and, due to its color, finished mineral wool from bituminous or anthracite ash is not suitable for use in exposed surfaces. Lignite and sub-bituminous ashes are, however, suitable (5).

4.2.4 Prefabricated Exterior Residential Walls

A potentially large construction application of fly ash is the manufacture of full length residential walls. This application has been successful in Yugoslavia, by casting a composite of 80 percent fly ash with cement or limestone (19). The cost estimates for this process are as low as one-tenth the cost of conventional brick or frame construction exterior residential walls. The final product is lightweight, termite and decay free, fire resistant, dimensionally stable, requires no special construction tools, and has better insulating qualities than conventional residential walls.

4.2.5. Mineral/Element Recovery

Potential U.S. markets exist for fly ash in the area of mineral and element recovery. Various processes are being explored to determine the feasibility of extracting alumina, titanium, magnetite, silica, lime, vanadium, uranium, and germanium from fly ash (3, 5, 19). Extraction of alumina has been successfully achieved in Poland and Hungary. Table 6 lists the percentages of mineral constituents of power plant ash.

TABLE 6. Mineral Resource Potential of Power Plant Ash (14)

Constituent	Percent
Silicon dioxide	45.7
Aluminum oxide	26.0
Ferric oxide	17.1
Calcium oxide	3.8
Sulfur trioxide	2.6
Potassium oxide	1.5
Titanium oxide	1.2
Magnesium oxide	1.2
Sodium oxide	0.6
Phosphorus oxide	0.3
Total	100.0

Limitations of the future marketability of mineral and element recovery from fly ash include the cost effectiveness of extraction and reprocessing techniques, and domestic production and import supplies of these materials. However, recognition of the following items may make fly ash mineral/element recovery more feasible in the future (5):

o increasing costs of mining, extraction, and transportation of primary metals,

- o need to reduce the volume of by-products requiring disposal, and
- o concern over foreign control of these minerals.

5. USE LIMITATIONS

Although the use of fly ash in construction applications has become generally accepted, in 1981 only about 13 percent of the total ash produced in the U.S. was utilized (4). The following sections delineate some of the limitations to the increased use of fly ash in construction materials.

5.1 FLY ASH VARIABILITY

The physical and chemical variability of fly ash, as described in section 2, is a significant market constraint to its use in construction materials. The physical and chemical characteristics of the ash cannot be predicted; therefore, to achieve an ash with uniform characteristics acceptable to commercial users, frequent on-line analyses at the power plant are required (5). Factors influencing the characteristics of the ash include type of coal, method of coal grinding, boiler load, and precipitator efficiency (14).

5.2 TRANSPORTATION COSTS

The second constraint that could impede the marketing of fly ash in construction material applications is transportation costs. Increased use of fly ash in construction materials would require that fly ash sources be located near large, populated areas in order to be economically transported to commercial users. Table 7 shows regional distribution of coal burned in the U.S. and the location and numbers of new coal fired units.

5.3 Existing Source of Raw Materials

A further possible market limitation for the expansion of fly ash utilization in construction materials is the existence of "own source materials" by the manufacturer (6). A manufacturer owning a quarry or mine to provide the raw materials for production would not be likely to purchase fly ash as a substitute for those raw materials.

5.4 Technical Limitations

Another major constraint to the widespread use of fly ash in construction materials is the lack of technical information on its performance in construction materials. Current performance tests and specifications apply for the most part to fly ash as a component of cement, and even these are either unduly restrictive or inadequate (1). This lack of technical data hampers the general acceptance of fly ash as a substitute raw material in construction materials, as potential users have no method for evaluating fly ash performance. The development of such tests is prerequisite to widespread acceptance of fly ash utilization.

6. USE BENEFITS

The use of fly ash as a raw material as opposed to mining and processing primary materials is attractive from the standpoint of energy consumption.

Table 7. Regional Distribution of Coal Burned in the U.S. and New Coal-Fired Units Planned Through 1986 (1, 24)

Geographic Area	States	Coal Burned tons (tonnes) x 10^3/year	Planned Units
New England	(ME, NH, VI, MA, RI, CT)	8206 (7449)	1
Middle Atlantic	(NY, NJ, PA)	40553 (36786)	7
East North Central	(OH, IN, IL, MI, WI)	83570 (75806)	50
West North Central	(MN, IA, MO, KS, NE, SD, ND)	13749 (12471)	40
South Atlantic	(MD, DE, VA, WV, NC, SC, GA, FL)	39502 (35832)	31
East South Central	(MS, AL, TN, KY)	33902 (30752)	30
West South Central	(MS, AL, TN, KY)	10 (9.07)	59
Mountain	(NM, AZ, NV, CO, UT, WY, MT, ID)	6644 (6027)	36
Pacific	(CA, OR, WA)	5 (4.54)	None

One short ton is equivalent to approximately 0.9071 tonnes as it is in most cases more energy efficient. This is illustrated by the energy savings realized in the manufacture of fly ash brick instead of clay brick. The largest factor contributing to energy savings is that fly ash is a pre-fired material; little additional heat work is required to form the ceramic bonds to produce a brick. Energy savings are estimated to be from 20 to 50 percent compared to clay brick.

Fly ash utilization is also attractive from the environmental viewpoint. Its assets in this area include:

- The recovery or reuse of a material that was historically considered a "waste product" can now be viewed as a useful by-product of coal combustion.
- Disposal of "waste products" by a utility can be extremely costly, and disposal sites are under increasingly negative scrutiny. Fly ash recovery can reduce the burden on solid waste disposal facilities.

Fly ash is generated in large quantities as small, ready-to-use particles with little or no processing required prior to its reuse as a raw material (14). Utilities should be able to profit economically by selling fly ash as a raw material to commercial users because costs associated with its disposal can be replaced with sales revenues.

8. SUMMARY

Fly ash utilization in construction materials would reduce the current fly ash burden on waste disposal facilities. Other benefits of increased fly ash utilization include energy savings acquired through the utilization of waste materials as a construction component as opposed to the mining and processing of primary materials. Energy savings for fly ash brick, for example, are estimated to range from 20 to 50 percent.

Construction applications may make use of fly ash's pozzolanic characteristics, its bulk characteristics, or its cenosphere fraction. Pozzolanic applications include use as an aggregate, landfill liner, brick raw material, and road pavement admix. Potential cenosphere applications include uses in plastic extenders, foams, coatings, paint, tapes, fire proofing materials, and insulation. Bulk applications include uses in construction backfills and embankments.

The primary limitations of fly ash utilization in construction materials include the variability of its physical and chemical properties. This variability plus a lack of technical information regarding its performance in construction materials have become a roadblock to development of technical standards for uses of fly ash in construction materials. Greater fly ash utilization in construction materials could be realized if technical specifications and engineering performance standards were developed for these materials. Transportation costs may also be a limitation to increased fly ash utilization.

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APPENDIX V. INTERLABORATORY STUDY OF ORGANIC EXTRACTION RECOVERIES

A statistical analysis was made on the organic extraction-recovery data obtained from interlaboratory experiments involving four laboratories. The percent recovery of 13 organic compounds was measured at 0 and 48 hours. Each laboratory was supposed to make duplicate percent recovery measurements at each condition, but this was not fully realized (see attached data sheets, tables 1-4). Our statistical analysis of the laboratory measurements for each compound and condition therefore consisted of a within-between analysis of variance for unbalanced data (1). The results of the analyses for each compound and condition are presented in tables 5-8, and give the weighted mean values, the standard errors of the weighted mean values, the components of standard deviation for the within laboratory replication variability, and the components of standard deviation for the between laboratory variability, respectively. (The components of standard deviation are the square roots of the components of variance.)

An examination of table 5 shows that generally similar recoveries were obtained for all compounds except acenaphthylene and 1-naphthylamine. The column averages listed at the bottom of the table therefore exclude these two compounds. A comparison of the column averages as well as of the individually listed values show that the 0 hour extractions allow about 90 percent recovery and tend to be about 3-10 percentage recovery units higher than those observed at 48 hours.

Table 6 shows that the standard errors are similar for all compounds. The table suggests no trends relative to the four experimental conditions. Average values were therefore taken for the standard errors for each compound and the results are given in the last column of the table. In general the standard error of the weighted mean for any given extraction condition is about 16 percentage recovery units.

Tables 7 and 8 list components of standard deviation that show no general or meaningful trends relative to the four experimental conditions. Average values were therefore taken for the components of standard deviation for each compound and the results are listed in the last column of the tables. The within and between laboratory component averages (17 and 22 percent, respectively) taken over all compounds except acenaphthylene and 1-naphthylamine, are given in the lower right-hand corner of the tables. As is frequently the case in interlaboratory studies, there exists a component for between laboratory variability above and beyond the variability within laboratories.

The overall average components of standard deviation listed in tables 7 and 8 can be used to obtain an estimate of the standard deviation of a single laboratory measurement.

$$s = (17^2 + 22^2)^{\frac{1}{2}} = 28\%$$

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Table 1. Synthetic Leachate Extraction Recovery Study

Spike Concentration: 10 ppb
Time: 0 hr

% Recovery

	Laboratory						
Analyte	NBS		A		B	C	
Phenol	46%	41%	125%	146%	87%	75%	86%
o-Cresol	84	73	73	69	67	75	92
Naphthylene	93	80	70	70	68	71	103
Quinoline	93	86	70	66	93	72	72
Acenaphthylene	93	83	---[a]	---	81	ND[b]	ND
1-Naphthylamine	19	37	---	---	18	ND	ND
2-Naphthol	91	76	105	60	108	62	41
Dibenzothiophene	90	84	92	68	101	62	51
Phenanthrene	90	84	95	77	100	72	52
Carbazole	84	86	132	79	108	88	62
Fluoranthene	82	82	122	74	86	110	70
Benzo(a)anthracene	79	92	125	70	189	84	96
Benzo(a)pyrene	75	90	ND	ND	186	ND	ND

[a] --- = not detected in extract

[b] ND = not determined

Table 2. Synthetic Leachate Extraction Recovery Study

Spike Concentration: 10 ppb
Time: 48 hr @ 4 °C

% Recovery

	Laboratory					
Analyte	NBS		A	B	C	
Phenol	46%	48%	31%	106%	75%	75%
o-Cresol	75	79	33	55	83	100
Naphthylene	92	92	61	49	63	79
Quinoline	71	56	69	86	82	82
Acenaphthylene	49	59	---[a]	65	ND[b]	ND
1-Naphthylamine	5	12	---	37	ND	ND
2-Naphthol	56	66	---	81	93	72
Dibenzothiophene	89	87	99	80	72	72
Phenanthrene	89	87	146	86	93	82
Carbazole	32	45	159	84	100	88
Fluoranthene	87	86	---	81	50	80
Benzo(a)anthracene	83	81	---	172	96	72
Benzo(a)pyrene	72	75	ND	167	ND	ND

[a] --- = not detected in extract

[b] ND = not determined

Table 3. Synthetic Leachate Extraction Recovery Study

Spike Concentration: 20 ppb
Time: 0 hr

	% Recovery						
	Laboratory						
Analyte	NBS		A		B	C	
Phenol	33%	38%	94%	100%	56%	81%	75%
o-Cresol	62	69	112	68	66	62	88
Naphthylene	75	80	114	82	56	63	119
Quinoline	68	73	108	83	98	77	134
Acenaphthylene	68	74	---[a]	---	54	ND[b]	ND
1-Naphthylamine	35	37	---	---	30	ND	ND
2-Naphthol	72	88	93	31	116	62	82
Dibenzothiophene	79	86	121	68	100	57	170
Phenanthrene	80	87	109	73	105	98	186
Carbazole	86	95	121	61	84	56	69
Fluoranthene	87	94	88	65	79	90	145
Benzo(a)anthracene	87	93	51	184	125	84	181
Benzo(a)pyrene	87	88	ND	ND	73	ND	ND

[a] --- = not detected in extract

[b] ND = not determined

Table 4. Synthetic Leachate Extraction Recovery Study

Spike Concentration: 20 ppb
Time: 48 hr @ 4 °C

% Recovery

	Laboratory						
Analyte	NBS		A		B	C	
Phenol	43%	46%	72%	116%	57%	38%	54%
o-Cresol	80	81	67	81	45	75	54
Naphthylene	100	106	71	84	41	103	103
Quinoline	100	94	66	92	61	119	103
Acenaphthylene	56	97	---[a]	---	49	ND[b]	ND
1-Naphthylamine	22	17	---	---	24	ND	ND
2-Naphthol	58	83	64	52	67	98	98
Dibenzothiophene	92	93	114	78	57	216	170
Phenanthrene	89	92	108	85	56	196	155
Carbazole	26	85	140	---	53	194	181
Fluoranthene	90	87	159	---	44	130	155
Benzo(a)anthracene	95	85	---	---	80	139	157
Benzo(a)pyrene	98	86	ND	ND	62	ND	ND

[a] --- = not detected in extract

[b] ND = not determined

Table 5. Weighted Means

	Experimental Condition				
Analyte	10 ppb 0 Hrs	10 ppb 48 Hrs	20 ppb 0 Hrs	20 ppb 48 Hrs	Row Averages
Phenol	87	65	67	61	70
o-Cresol	76	65	75	67	71
Naphthylene	79	69	84	81	78
Quinoline	81	75	92	88	84
Acenaphthylene	56	40	42	42	45
1-Naphthylamine	15	15	22	14	17
2-Naphthol	79	56	78	74	72
Dibenzothiophene	80	85	97	111	93
Phenanthrene	83	102	105	105	99
Carbazole	91	94	82	95	91
Fluoranthene	89	59	92	95	84
Benzo(a)anthracene	113	84	115	79	98
Benzo(a)pyrene	134	120	80	78	103
Average excluding acenaphthylene & 1-naphthylamine values.	90	80	88	85	86

Table 6. Standard Errors of the Weighted Means

Analyte	Experimental Condition 10 ppb 0 Hrs	10 ppb 48 Hrs	20 ppb 0 Hrs	20 ppb 48 Hrs	Row Averages
Phenol	19	16	13	12	15
o-Cresol	4	13	7	7	8
Naphthylene	5	9	9	15	10
Quinoline	6	5	9	11	8
Acenaphthylene	28	20	21	23	23
1-Naphthylamine	8	11	11	7	9
2-Naphthol	11	19	10	9	12
Dibenzothiophene	9	6	14	29	15
Phenanthrene	8	15	14	25	16
Carbazole	9	25	8	33	19
Fluoranthene	7	20	10	22	15
Benzo(a)anthracene	24	35	19	30	27
Benzo(a)pyrene	52	47	7	15	30
Average excluding acenaphthylene & 1-naphthylamine values.					16

Table 7. Components of Standard Deviation for Within Laboratory Replication Variability

Analyte	Experimental Condition 10 ppb 0 Hrs	10 ppb 48 Hrs	20 ppb 0 Hrs	20 ppb 48 Hrs	Row Averages
Phenol	10	1	4	19	9
o-Cresol	8	9	18	10	11
Naphthylene	14	8	24	6	13
Quinoline	3	7	23	13	12
Acenaphthylene	5	7	3	20	9
1-Naphthylamine	9	5	1	2	4
2-Naphthol	21	12	27	11	18
Dibenzothiophene	11	1	38	24	19
Phenanthrene	11	6	38	19	19
Carbazole	22	9	22	62	29
Fluoranthene	19	15	25	59	30
Benzo(a)anthracene	22	12	51	8	24
Benzo(a)pyrene	11	2	1	8	6
Average excluding acenaphthylene & 1-naphthylamine values.					17

Table 8. Components of Standard Deviation for Between Laboratory Variability

	Experimental Condition				
Analyte	10 ppb 0 Hrs	10 ppb 48 Hrs	20 ppb 0 Hrs	20 ppb 48 Hrs	Row Averages
Phenol	37	33	27	19	29
o-Cresol	3	24	0	12	10
Naphthylene	0	17	0	29	12
Quinoline	12	9	0	19	10
Acenaphthylene	49	34	37	36	39
1-Naphthylamine	13	19	19	13	16
2-Naphthol	15	37	0	15	17
Dibenzothiophene	16	11	0	55	21
Phenanthrene	13	29	0	48	23
Carbazole	0	49	0	45	24
Fluoranthene	0	37	5	0	11
Benzo(a)anthracene	44	69	0	61	44
Benzo(a)pyrene	73	66	10	20	42
Average excluding acenaphthylene & 1-naphthylamine values.					22

Table 9. Yield Equations Derived from Data of Table 5
(C_x in PPB; t in hours)

Analyte	Yield (%)	Std. Error of Estimate
Phenol	$(95.0-1.2C_x-0.29t)$	8.0
o-Cresol	$(74.8+0.05C_x-0.20t)$	1.5
Naphthylene	$(68.8+0.85C_x-0.14t)$	3.5
Quinoline	$(68.5+1.2C_x-0.10t)$	1.0
1-Naphthol	$(65.8+0.85C_x-0.28t)$	9.5
Dibenzothiophene	$(56.2+2.1_5C_x+0.20t)$	4.5
Phenanthrene	$(75.2+1.25C_x+0.20t)$	9.5
Carbazole	$(92.5-0.4C_x+0.17t)$	5.0
Fluoranthene	$(61.3+1.9_5Cx-0.28t)$	16.5
Benzo(a)anthracene	$(116-0.15C_x-0.68t)$	3.5
Benzo(a)pyrene	$(179-4.8C_x-0.17t)$	6.0

Valid for $10 \leq C_x \leq 20$

$0 \leq t \leq 48$

APPENDIX VI. HAZARDOUS WASTE CHARACTERIZATION

(Representative Activities FY 1982)

Synthetic Aqueous Leachate Extraction Recovery Study

The initial phase of the Waste Characterization Project involved determining the extraction recovery of selected organic compounds from a synthetic aqueous leachate at the ppb level. The synthetic aqueous leachates were prepared by adding aliquots (1 or 2 mL) of a methanolic solution of 14 organic compounds to one liter of high-purity HPLC water in clean teflon jars to produce solutions at the 10 and 20 ppb levels. These samples were extracted and analyzed according to the procedure developed at PETC on January 21-23, 1981. Four laboratories -- NBS, Pittsburgh Energy Technology Center, Argonne National Laboratory, and Oak Ridge National Laboratory -- participated in an interlaboratory study to assess the analytical variability in determining the target compounds in the synthetic leachates. The results of this limited round robin study presented enough analytical difficulties that repetition of the extraction and analysis of a synthetic aqueous leachate with tightening of the analytical protocol was desired. A second synthetic aqueous leachate solution, containing 16 compounds, was prepared and analyzed according to the revised "Agreed Upon Analytical Method" as follows:

> Approximately 10 mg of each compound was weighed on a Cahn electrobalance and transferred to a clean 1 L volumetric flask partially filled with methanol. The concentration of each compound added is given in table 1. The solution was brought to volume with methanol and sonicated for 15 minutes to ensure complete dissolution of all compounds. The flask was covered with aluminum foil to protect the contents from exposure to light and stored at 4 °C until used. Synthetic aqueous leachates were prepared by adding 1.0 mL of the methanolic solution to 1 L of Baker InstraAnalyzed water, giving a solution of approximately 10 ppb of each analyte. The synthetic leachates were prepared, extracted, and analyzed in triplicate by gas chromatography and gas chromatography/mass spectrometry according to the revised analytical method.

Gas Chromatographic Analysis of Synthetic Aqueous Leachate Extracts

One to two µL aliquots of the synthetic aqueous leachate extracts were analyzed by gas chromatography with flame ionization detection. Chromatographic separations were carried out on a 30 m x 0.25 mm i.d. SE-52 fused silica capillary column. Hydrogen was used as a carrier gas at an inlet pressure of 27 psig. The column was temperature programmed from 60 °C to 300 °C at a rate of 4 °C/minute. Under these conditions, all of the analytes were resolved from each other except for the dibenzothiophene and

4-aminobiphenyl, which co-elute, and the 2,3,4,5-tetrachlorobiphenyl (internal standard) and fluoranthene which are only partially resolved.

Table 1. Concentrations of Compounds in Second Synthetic Methanolic Leachate Solution.

Compound	Concentration (mg/L)
2-picoline	10.11
phenol	10.72
o-cresol	12.77
naphthalene	9.98
quinoline	11.96
n-tetradecane	10.54
1,4-naphthoquinone	10.50
acenaphthylene	9.53
2-naphthol	9.48
1-naphthylamine	10.17
4-aminobiphenyl	8.94
dibenzothiophene	10.56
phenanthrene	10.12
carbazole	10.59
fluoranthene	11.09
benz[a]anthracene	10.40

Response factors for each of the analytes compared to the 2,3,4,5-tetrachlorobiphenyl internal standard were determined from a gravimetric solution of the analytes and the tetrachlorobiphenyl (see table 2). Concentrations of the analytes in the extracts and the percent recoveries were determined from the integrated analyte peak areas, the integrated internal standard peak area, and the experimentally determined response factors. These values are presented in table 3. The 2-picoline was not determined by GC-FID due to numerous interfering peaks in the early portion of the chromatogram. The 2-picoline recovery was determined in later

Table 2. Gas Chromatographic Determination of Analytes in a Synthetic Aqueous Leachate at the 10 ppb Level.

Analyte	Average Peak Retention Time (min.)[a]	Response Factor[b]
2-picoline	---	---
phenol	9.34 ± 0.006 (n = 3)	2.146
o-cresol	12.24 ± 0.000	1.675
naphthalene	16.43 ± 0.006	2.469
quinoline	19.50 ± 0.006	1.484
n-tetradecane	25.23 ± 0.000	2.398
1,4-naphthoquinone	25.71 ± 0.000	1.106
acenaphthylene	27.04 ± 0.000	2.433
2-naphthol	29.20 ± 0.000	1.399
1-naphthylamine	29.81 ± 0.000	1.086
4-aminobipheny dibenzothiophene co-elute	36.45 ± 0.000	1.330
phenanthrene	37.22 ± 0.006	2.500
carbazole	38.74 ± 0.000	1.424
2,3,4,5-tetrachlorobiphenyl	44.59 ± 0.006	1.000
fluoranthene	44.69 ± 0.000	2.421
benz[a]anthracene	53.71 ± 0.012	1.724

[a] Column: 30 m x 0.25 mm SE-52 fused silica capillary column

T program: 60° initial for 4 minutes, program @ 4°/minute at 300 °C

Carrier gas: H_2 @ 27 psig

[b] Response Factor:

$$\frac{\text{analyte peak area/weight of analyte}}{\text{2,3,4,5-tetrachlorobiphenyl peak area/weight of 2,3,4,5-tetrachlorobiphe}}$$

Table 3. Gas Chromatographic Determination of Extraction Recoveries of Analytes from a Synthetic Aqueous Leachate.

Analyte	Original Amount Added (μg/L)	Amount Extracted (μg)	% Recovery
2-picoline	10.11	---	---
phenol	10.72	5.77 ± 1.4	54
o-cresol	12.77	8.54 ± 0.7	67
naphthalene	9.88	8.68 ± 0.9	88
quinoline	11.96	11.46 ± 2.1	96
n-tetradecane	10.54	7.00 ± 1.3	66
1,4-naphthoquinone	10.50	0.64 ± 0.4	6
acenaphthylene	9.53	9.19 ± 1.5	96
2-naphthol	9.48	4.75 ± 1.9	50
1-naphtylamine	10.17	0.51 ± 0.1	5
4-aminobiphenyl	8.94		
		17.84 ± 3.2	92
dibenzothiophene	10.56[a]		
phenanthrene	10.12	10.15 ± 1.8	100
carbazole	10.59	12.92 ± 2.5	122
fluoranthene	11.09	11.24 ± 2.0	101
benz[a]anthracene	10.40	11.34 ± 1.9	109

[a] 4-aminobiphenyl and dibenzothiophene co-elute; amount extracted and percent recovery represent a mean for both compounds.

experiments by GC/MS with selected ion monitoring. The 4-aminobiphenyl and dibenzothiophene were not resolved chromatographically, and therefore, the percent recovery represents an average recovery for the two compounds together. GC/MS experiments, to be discussed later, indicate that the dibenzothiophene is recovered much more efficiently (∿100 percent) than the 4-aminobiphenyl (∿10 percent).

GC/MS Analysis of Synthetic Aqueous Leachate Extracts

The synthetic aqueous leachate extracts were analyzed by GC/MS with selected ion monitoring. Gas chromatographic separations were carried out on a 30 m x 0.25 mm i.d. SE-52 fused silica capillary column. Helium was used as a carrier gas at an inlet pressure of 10 psig. The column was temperature programmed from 60° to 275° at a rate of 4 °C/minute and was interfaced directly to the ion source of the mass spectrometer. The mass spectrometer was operated in the EI mode with an ionizing energy of 70 eV. Ion source tuning parameters were set using PFTBA as a reference compound.

The synthetic leachate extracts were analyzed using commercial software. A characteristic, intense ion for each analyte (in most cases, the molecular ion, M+) was monitored with a dwell time of 100 ms. The ion monitored for each analyte, along with the chromatographic retention time are shown in table 4. The selectivity of the SIM detection allowed each analyte to be determined free of interferences, even in cases where analytes were not resolved chromatographically. The dibenzothiophene (m/z 184) and 4-aminobiphenyl (m/s 169) co-elute at 31 minutes, for example; yet each is determined independently of the other. Each extract was analyzed in triplicate, and selected ion record peak areas were integrated after each run and ratios of the analytes to 2,3,4,5-tetrachlorobiophenyl computed.

Concentrations of analytes in the extracts were determined by the method of standard additions. 100 µL aliquots of each extract were spiked with a known amount of each analyte detected in the SIM analysis of the sample extract. The samples were then reanalyzed by GC/MS with SIM under identical chromatographic and mass spectrometric conditions. Single ion record peak areas were integrated for each analyte after each run and ratios of the analyte peak area to the 2,3,4,5-tetrachlorobiphenyl internal standard computed. Percent recoveries were calculated based on the amount of analyte extracted (from the 2-point standard addition) and the amount of analyte originally added to the 1 L water sample. These values are shown in table 5. The unusually high recoveries are believed to be due to a volumetric error during the solvent concentration step. It is critical that the volume of the organic extract be concentrated to 1.0 mL, exactly. Concentration to volumes slightly less than 1.0 mL will lead to percent recoveries greater than the actual values. There are additional volumetric errors possible during the extraction and analysis scheme, some of which are noted below. Of particular importance are the initial solvent concentration step and the removal of exactly 100 µL of the sample for the standard addition quantitation. We have experienced some difficulty in

Table 4. GC/MS SIM Determination of Analytes in a Synthetic Aqueous Leachate.

Analyte	Ion Monitored, m/z	Retention Time (min.)[a]
2-picoline	93.0	3.3 ± 0.0
phenol	94.0	6.5 ± 0.0
o-cresol	108.0	8.6 ± 0.0
naphthalene	128.0	13.0 ± 0.0
quinoline	129.0	14.8 ± 0.0
n-tetradecane	57.0	20.5 ± 0.0
1,4-naphthoquinone	158.0	20.8 ± 0.0
acenaphthylene	152.0	22.1 ± 0.0
2-naphthol	144.0	24.3 ± 0.0
1-naphthylamine	143.0	24.8 ± 0.0
4-aminobiphenyl	169.0	31.3 ± 0.0
dibenzothiophene	184.0	31.3 ± 0.0
phenanthrene	178.0	32.1 ± 0.0
carbazole	167.0	33.7 ± 0.0
2,3,4,5-tetrachlorobiphenyl	292.0	39.5 ± 0.0
fluoranthene	202.0	39.5 ± 0.0
benz[a]anthracene	228.0	48.3 ± 0.0

[a] Column: 30 m x 0.25 mm i.d. SE-52 fused silica capillary column

T program: 60° initial, programmed @ 4°/minute to 275 °C

Carrier gas: He @ 10 psi

Retention times determined on HP 5985 GC/MS system which gives retention data to the nearest 0.1 minute.

Table 5. GC/MS SIM Determination of Extraction Recoveries of Analytes from a Synthetic Aqueous Leachate.

Analyte	Original Concentration in 1 L H_2O (µg/L)	µ Extracted	% Recovery
2-picoline	10.11	5.90 ± 0.5	58 ± 5 (n = 3)
phenol	10.72	10.19 ± 1.4	95 ± 13
o-cresol	12.77	14.43 ± 2.4	113 ± 18
naphthalene	9.98	9.99 ± 1.4	100 ± 14
quinoline	11.96	13.27 ± 1.6	111 ± 14
n-tetradecane	10.54	ND[a]	ND[a]
1,4-naphthoquinone	10.50	0.04 ± 0.0	0.4 ± 0.1
acenaphthylene	9.53	10.48 ± 1.0	110 ± 11
2-naphthol	9.48	6.01 ± 3.2	63 ± 33
1-naphthylamine	10.17	0.44 ± 0.1	4 ± 1
4-aminobiphenyl	8.94	0.92 ± 0.1	10 ± 1
dibenzothiophene	10.56	13.13 ± 1.6	124 ± 16
phenanthrene	10.12	12.79 ± 1.5	126 ± 15
carbazole	10.59	12.85 ± 1.0	121 ± 9
fluoranthene	11.09	13.46 ± 1.3	121 ± 12
benz[a]anthracene	10.40	10.44 ± 0.8	100 ± 7

[a] ND = not determined

adding 1.0 μL aliquots of the 2,3,4,5-tetrachlorobiphenyl internal standard solution with good precision. In a separate series of experiments, three 1.0 mL aliquots of the methanol synthetic leachate solution were placed into clean vials. 1.0 μL of a 10 μg/μL solution of 2,3,4,5-tetrachlorobiphenyl was added to each vial with a 1.0 μL Hamilton syringe. The samples were analyzed by GC/MS with SIM and peak area ratios of the analytes to the 2,3,4,5-tetrachlorobiphenyl computed. The observed relative precision in the ratios fell in a range from 5-25 percent (see table 6). This degree of imprecision may cause problems with the quantitative data on real world samples.

Possible Volumetric Errors in Extraction/Analysis Scheme

1.0 mL MeOH solution
↓
1.0 L H_2O

extract, concentrate
↓
1.0 mL extract exactly!

add 1.0 μL 2,3,4,5-tetrachlorobiphenyl
internal standard

GC/MS SIM Analysis

↓
100 μL aliquot (1/10th of sample) exactly!

↓ 10 μL standard addition solution

GC/MS SIM Analysis

GC/MS Analysis of SRC II Vacuum Still Bottom Bulk Aqueous Leachates

Aqueous leachates of the SRC II Vacuum Still Bottom (VSB) material were prepared by the Laramie Energy Technology Center using EPA extraction procedure (EP) and ASTM leaching procedures. Two EP aqueous leachates and two ASTM aqueous leachates were extracted and analyzed by gas chromatography with flame ionization detection, and by gas chromatography/mass spectrometry in the SIM and full-scanning modes.

The resultant chromatograms show a number of minor peaks which elute at the known retention times of the target analytes. The samples were therefore analyzed by gas chromatography/mass spectrometry, in the full-scanning mode to confirm the presence of the analytes, and in the SIM mode for quantitation.

Total ion chromatograms were prepared of the SRC II VSB EP and ASTM-A bulk leachate extracts. The major peaks in the chromato-

Table 6. GC/MS Analysis of MeOH Synthetic Leachate + 2,3,4,5-Tetrachlorobiphenyl Solutions[a].

	- Analyte/2,3,4,5-Tetrachlorobiphenyl -			
Analyte	Sample 6592	Sample 6593	Sample 6594	X ± SD (RSD)
2-picoline	2.43	1.71	1.52	1.89 ± 0.48 (25%)
phenol	2.61	2.12	1.76	2.16 ± 0.42 (20%)
o-cresol	2.49	2.01	1.67	2.06 ± 0.41 (20%)
naphthalene	7.24	5.84	5.00	6.03 ± 1.13 (19%)
quinoline	5.78	4.34	3.96	4.69 ± 0.96 (20%)
n-tetradecane	2.35	2.02	1.76	2.04 ± 0.29 (14%)
1,4-naphthoquinone	1.52	1.36	1.12	1.33 ± 0.20 (15%)
acenaphthalene	6.61	5.55	4.87	5.67 ± 0.88 (15%)
2-naphthol	2.92	2.46	2.19	2.52 ± 0.37 (15%)
1-naphthylamine	1.82	1.74	1.39	1.65 ± 0.23 (14%)
4-aminobiphenyl	0.97	0.90	0.89	0.92 ± 0.04 (5%)
dibenzothiophene	6.74	5.35	5.07	5.72 ± 0.89 (16%)
phenanthrene	7.13	5.65	5.31	6.03 ± 0.97 (16%)
carbazole	6.54	5.05	5.05	5.54 ± 0.86 (15%)
fluoranthene	7.91	6.23	5.90	6.68 ± 1.08 (16%)
benz[a]anthracene	5.16	3.56	3.86	4.19 ± 0.85 (20%)

[a] Solutions prepared by adding 1.0 µL f a 2,3,4,5-tetrachlorobiphenyl solution to 1.0 mL of a MeOH synthetic leachate solution.

grams are phthalates and the fluorophenol, azulene, and 2,3,4,5-tetrachlorobiphenyl internal standards. A number of substituted phenols were also detected in the sample extracts. Of particular interest are the chlorinated phenol at approximately 21 minutes and the brominated phenol at 23 minutes, tentatively identified from their mass spectra and confirmed by a library search. Mass spectra of these compounds were also taken. The presence of halogens is clearly indicated by the characteristic isotope clusters in the spectra. A blank leachate sample prepared under identical conditions was not supplied, so it is impossible to state that these compounds are definitely associated with the SRC II VSB leachate samples. The EP and ASTM-A bulk leachates of the SRC II VSB were then analyzed by GC/MS with SIM detection. Individual analytes were determined based on the analyte to 2,3,4,5-tetrachlorobiphenyl ratios and comparison with a gravimetrically prepared standard run under identical conditions. The concentrations of analytes detected in the SRC II VSB EP bulk leachate are shown in table 7. The concentrations fell in a range from approximately 1 part per billion for phenol down to a barely detectable 23 parts per trillion for fluoranthene. In all cases, the observed concentrations are well below the 10 parts per billion threshold value. The extremely low concentrations are somewhat surprising, especially in view of the known aqueous solubilities of a number of the analytes (see table 8). Fluoranthene, for example, has an aqueous solubility of 200 parts per billion at 25 °C, yet was detected at only 23 parts per trillion; phenanthrene has an aqueous solubility of approximately 1 part per million, yet was detected at only 46 parts per trillion. Both of these compounds were known to be present in the SRC II VSB material. Concentrations of the analytes detected in the ASTM leachates are somewhat higher than in the EP leachates (see table 9) but still well below the 10 parts per billion threshold. It seems likely, therefore, that there is some loss of organics during the sample handling and extraction steps. The round robin exercises on the synthetic leachates showed that we are able to efficiently extract the analytes from water at the 10 parts per billion level. These experiments were concerned with measuring the extraction efficiency of the method only. We did not look into losses due to adsorption on leaching vessel walls, filters, etc. Substantial losses may be occurring during the filtration steps, especially on the 0.45 micron filters used in the preparation of the aqueous leachates.

NBS has now used this method for the extraction and analysis of two synthetic leachates and two SRC II Vacuum Still Bottom aqueous leachates. Given this degree of experience with the method, the following observations are noteworthy:

1) The method, when applied conscientiously, can be used to efficiently extract and detect the target compounds from aqueous leachates at the 10 ppb level. Nevertheless, losses as discussed above are possible. The only analytes which present some difficulties are the 1,4-naphthoquinone and the 1-naphthylamine. The phenols are all recovered 50 percent or better, and most of the

polynuclear aromatic hydrocarbons are extracted quantitatively at the µg/L level.

2) Some tightening of the quantitation scheme seems necessary in order to assure accurate quantitative results. Possible sources of error in the GC/MS determination of extraction recoveries have already been discussed. Most of the volumetric errors can be avoided, although the ability to accurately add 1.0 µL volumes of the internal standard solution to the sample extracts may continue to introduce imprecision and errors in the quantitative data. The 2-point standard addition quantitation should be modified to a 3-point standard addition. The linearity (or lack of linearity) of the curve in a 3-point standard addition. The linearity (or lack of linearity) of the curve in a 3-point standard addition provides some indication of how accurately the standard additions are made. The 2-point standard addition provides no built-in check of this type.

3) Losses of organics during the leaching and subsequent filtration steps must be investigated. The detection of polynuclear aromatic hydrocarbons in the aqueous leachates of the SRC II Vacuum Still Bottom material at levels several orders of magnitude lower than their known aqueous solubilities suggests that substantial losses may be occurring.

Table 7. Concentrations of Compounds in EP Bulk Leachate of

SRC II Vacuum Still Bottom Material.

Analyte	Concentration (µg/L)
phenol	1.09 ± 0.08 (n = 2)
o-cresol	0.175 ± 0.05
naphthalene	0.203 ± 0.03
1,4-naphthoquinone	0.078 ± 0.013
phenanthrene	0.046 ± 0.002
carbazole	0.460 ± 0.09
fluoranthene	0.023 ± 0.01

Table 8. Aqueous Solubility of Selected Organics Associated With Hazardous Waste Leachates.

Compound	Aqueous Solubility at 25 °C
2-picoline	very soluble[a]
phenol	76.4 mg/g[b]
o-cresol	2.72 mg/g[b]
naphthalene	32000 ng/g[c]
quinoline	sparingly soluble[d]
1,4-naphthoquinone	sparingly soluble[d]
acenaphthylene	---
acenaphthene	3930 ng/g[c]
2-naphthol	1.00 mg/g[d]
1-naphthylamine	1.69 mg/g[d]
4-aminobiphenyl	slightly soluble[a]
dibenzothiophene	soluble[a]
phenanthrene	1003 ng/g[c]
carbazole	insoluble[d]
fluoranthene	200 ng/g[c]
benz[a]anthracene	9.4 ng/g[c]
benzo[e]pyrene	2 ng/g[c]
benzo[a]pyrene	1.6 ng/g[c]
perylene	< 1 ng/g[c]

[a] CRC Handbook of Chemistry and Physics, 48th edition.

[b] Octanol/Water Partition Coefficients and Aqueous Solubilities of Organic Compounds, NBSIR 81-2406.

[c] W. E. May, Solubility Behavior of Polycyclic Aromatic Hydrocarbons in Aqueous Systems, ACS Advances in Chem. Series, #185, 7, pp. 143-192.

[d] Merck Index, 9th edition, Merck and Company, Inc., Rahway, NJ.

Table 9. Concentrations of Compounds in ASTM Bulk Leachate of SRC II Vacuum Still Bottom Material.

Analyte	Concentration (µg/L)
2-picoline	0.24 ± 0.02 (n = 2)
phenol	6.68 ± 1.41
o-cresol	1.63 ± 0.27
naphthalene	0.38 ± 0.06
quinoline	0.39 ± 0.01
1,4-naphthoquinone	0.15 ± 0
dibenzothiophene	0.021 ± 0.01
phenanthrene	0.057 ± 0.01
carbazole	0.76 ± 0.16
fluoranthene	0.016 ± 0.006

ORGANIC LEACHATES - STATISTICAL ANALYSIS OF INTERLABORATORY DATA

by

Robert C. Paule

Two different interlaboratory experiments with organic leachates have been completed. The following is a report on the statistical analysis of the measurements from these experiments.

Experiment I

In the first experiment each laboratory was asked to take 3 one-liter portions of water and add a 10 ppb spike of 19 specific organic compounds. Each one-liter portion (standards #1, 2, and 3) was individually extracted, concentrated, and analyzed 3 times each by GC-MS and by GC measurement techniques. Averages for the triplicate measurements were reported for each standard, and for each method of analysis (GC-MS and GC). These data are given in tables 1 and 2.

A within- and between laboratory analysis of variance [1,2][1] was made for each compound and analytical technique (see columns 2-9 of table 3). The average concentration and its standard error (standard deviation of the average) are reported for each compound, along with the within- and the between laboratory components of standard deviation. At the bottom of the table the average results are reported for compounds with greater than 50 percent recovery. The averages (8.15 and 7.67 ppb) for the concentrations given at the bottom of the table show that essentially the same results are obtained by both the GC-MS and the GC measurement techniques. This is further confirmed by the data in column 10 which gives the individual compound concentration differences between the two measurement techniques. These differences are not statistically significant, and are quite evenly distributed about zero.

Inspection of the average components of standard deviation at the bottom of columns 4 and 5, and of 8 and 9, show that the within- and the between laboratory components of standard deviation are of similar magnitude. The two components for the GC-MS measurements tend to be slightly larger than for the GC measurements. All four components, however, can be adequately approximated by a value of 2 ppb. Thus, the standard error of a single laboratory's measurements on a single solution is about 3 ppb, or 30 percent.

The overall recovery and the associated standard error for the individual compounds from both measurement techniques are reported in columns 11 and 12. The values given in these columns are based on the use of a weighted average [1]. The recovery is about 8 ppb. Since a 10 ppb spike was used in the experiment, this corresponds to an overall recovery of 80 percent.

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[1] Figures in brackets indicate the literature references at the end o this paper.

The above summary statements are made for the large majority of compounds that had greater than 50 percent recovery. Note, however, that four compounds listed in table 3 had less than 50 percent recovery. These compounds are: n-tetradecane, 1-naphthylamine, 1-4-naphthoquinone, and 4-aminobiphenyl. The recoveries of these four compounds are quite low, and need to be reviewed by the chemists of this interlaboratory exercise.

Experiment II

In the second experiment each laboratory made leachings from SRC-II vacuum still bottom waste using methods A and EP. The measurement data are reported in table 4, and the statistical analysis is presented in table 5. This latter table gives the average compound concentrations, the standard errors, and the standard deviations for single laboratory results and associated coefficients of variation. The relative precisions for the two leaching methods are essentially the same (coefficient of variation $\sim$ 55 percent). The method A leaching procedure extracts considerably higher concentrations for seven of the eight compounds which were jointly measured. The differences in concentration between methods A and EP are listed in column 10. The standard deviations of these differences and the associated Student t values are given in columns 11 and 12. The seven positive t values reflect higher method A leachate concentrations. They border on being statistically significant.

References

[1] Paule, R. C. and Mandel, J., Consensus Values and Weighting Factors, J. of Research of the NBS, 87, No. 5, Sept.-Oct. 1982.

[2] Mandel, J. and Paule, R. C., Interlaboratory Evaluation of a Material with Unequal Numbers of Replicates, Anal. Chem., 42, 1194-7 (1970), and Correction, Anal. Chem., 43, 1287 (1971).

Table 1. Synthetic Leachate #2 C-MS Results (in ppb)
Each Value is the Average Value of 3 Determinations.

Compound	Argonne Std. #1	Argonne Std. #2	Argonne Std. #3	Ames Std. #1	Ames Std. #2	Ames Std. #3	NBS Std. #1	NBS Std. #2	NBS Std. #3
picoline	4.8	7.0	2.4	4.9	5.2	5.8	6.4	5.8	5.4
phenol	11.7	10.7	22.8	3.2	2.9	2.5	8.1	9.8	10.6
o-cresol	14.9	5.8	8.7	4.2	6.1	4.1	9.2	11.9	12.8
naphthalene	15.1	4.7	11.5	7.6	7.9	7.4	8.6	10.2	11.3
quinoline	6.3	5.8	10.5	6.4	6.7	6.1	9.7	11.1	12.5
n-tetradecane	3.7	3.4	5.6	4.3	3.6	6.2	x[a]	x	x
acenaphthylene	4.4	5.7	14.5	7.4	8.0	7.0	10.0	10.9	12.2
2-naphthol	1.6	4.1	5.8	5.8	5.9	3.9	2.9	6.5	9.6
1-naphthylamine	9.8	1.7	3.8	2.4	2.1	1.4	.32	.45	.51
dibenzothiophene	3.4	5.5	9.7	8.9	9.5	8.1	11.4	11.7	14.2
phenanthrene	3.5	5.4	10.1	8.2	8.8	7.3	11.5	12.2	14.3
carbazole	2.0	5.3	8.0	7.8	8.7	6.4	13.2	11.7	11.5
BaA	1.7	6.1	7.8	6.8	8.0	5.1	10.9	9.8	9.5
fluorophenol	x	x	x	5.8	4.4	4.5	x	x	x
azulene	x	x	x	5.1	5.4	4.5	x	x	x
1,4-naphthoquinone	-[b]	-	-	0.1	0.3	0.3	.05	.05	.03
4-aminobiphenyl	-	-	-	2.9	2.8	1.6	1.05	.93	1.12
fluoranthene	2.1	4.7	11.2	7.9	8.8	6.3	13.3	12.1	10.9
caproic acid	13.8	4.7	5.7	-	-	-	x	x	x

[a] Not determined

[b] Not detected

Table 2. Synthetic Leachate #2 - GC-MS Results.
All Individual Values are Averages Based on Three Determinations.

	ppb Amount Found in the Water											
	Argonne			Ames			BETC			NBS		
Compound	Std. #1	Std. #2	Std. #3	Std. #1	Std. #2	Std. #3	Std. #1	Std. #2	Std. #3	Std. #1	Std. #2	Std. #3
picoline	5.2	8.9	11.1	6.3	6.0	6.4	12.8	9.0	5.1	x	x	x
phenol	10.3	11.8	26.8	3.7	3.2	3.0	6.0	8.0	3.3	6.73	5.23	4.20
o-cresol	5.3	6.7	7.5	7.7	7.5	7.2	9.7	9.7	4.6	6.83	7.10	6.08
naphthalene	5.1	6.1	7.3	9.0	8.8	9.1	12.1	12.5	6.3	8.40	9.73	7.97
quinoline	6.9	7.6	16.8	5.7	6.4	9.3	15.8	13.6	5.0	9.81	11.24	7.69
n-tetradecane	3.7	4.0	4.3	5.1	6.9	3.6	8.4	9.5	4.9	6.43	7.99	5.50
acenaphthylene	5.6	5.5	6.4	8.9	8.3	7.7	10.2	9.9	5.2	8.98	11.48	8.46
2-naphthol	6.2	7.9	10.1	8.1	8.3	8.7	5.9	5.6	3.5[a]	2.65	6.27	6.11
1-naphthylamine	1.0	2.1	2.5	7.5	6.3	8.8	2.3	-[b]	-	0.58	9.58	0.34
dibenzothiophene	4.2	3.9	5.2	9.0	9.5	8.7	7.6	6.8	3.7	Δ	Δ	Δ
phenanthrene	8.0	7.0	8.5	8.3	9.8	9.2	8.2	7.7	9.3	9.25	12.09	8.74
carbazole	8.8	9.7	12.4	8.8	9.6	9.1	8.1	6.4	11.6	11.53	14.82	10.25
BaA	6.5	7.1	7.2	8.2	10.3	9.7	6.4	5.0	5.5	10.28	13.01	9.43
fluorophenol	x[c]	x	x	5.4	4.6	4.5	7.5	8.4	4.1	x	x	x
azulene	x	x	x	8.6	8.3	8.8	11.3	9.9	4.8	x	x	x
1,4-naphthoquinone	-	-	-	-	-	-	4.2	4.0	2.0[a]	0.51	-	0.70
4-aminobiphenyl	-	-	-	2.2	0.5	5.0	-	-	-	Δ	Δ	Δ
fluoranthene	Δ[d]	-	-	8.6	8.9	9.4	6.9	5.3	4.5	9.29	12.22	8.89
caproic acid	-	-	-	x	x	x	-	-	-	x	x	x

[a] Average value of two measurements

[b] Not detected

[c] Not determined

[d] Cannot be calculated due to co-elution

Table 3. Statistical Analysis of Synthetic Laechate #2.

	GC-MS				GC						
Compound (μg/ℓ)	Average	Std. Error	s(within)[a]	s(between)[b]	Average	Std. Error	s(within)[a]	s(between)[b]	Average, GC-MS minus GC	Overall Average	Std. Error
1. picoline	5.97	.42	1.12	.32	7.86	.91	2.72	0	-1.89	6.74	.93
2. phenol	9.16	3.52	3.95	5.65	7.69	2.92	4.76	5.16	1.47	8.29	2.25
3. o-cresol	8.63	1.96	2.97	2.94	7.16	.43	1.50	0	1.47	7.23	.42
4. napthalene	9.37	1.01	3.03	0	8.53	.86	1.88	1.34	.84	8.88	.65
5. quinoline	8.34	1.42	1.70	2.25	9.65	1.14	3.94	0	-1.31	9.14	.89
6. n-tetradecane	4.47	.48	1.17	0	5.86	.79	1.59	1.29	-1.39	5.02	.68
7. acenaphthylene	8.90	1.09	3.25	.17	8.05	.80	1.66	1.28	.85	8.35	.64
8. 2-naphthol	5.12	.78	2.23	0	6.61	.93	1.57	1.62	-1.49	5.78	.74
9. 1-naphthylamine	2.50	1.37	2.45	1.92	2.67	1.65	.99	3.25	-.17	2.57	1.05
10. dibenzothiophene	9.16	1.81	2.09	2.89	6.51	1.36	1.27	2.24	2.65	7.57	1.30
11. phenanthrene	9.02	1.89	2.18	3.02	8.84	.47	1.13	.69	.18	8.85	.46
12. carbazole	8.29	2.06	1.94	3.38	9.51	1.22	1.75	2.22	-1.22	9.19	1.05
13. BaA	7.30	1.44	2.05	2.20	8.22	1.19	1.15	2.28	-.92	7.85	.92
14. fluorophene	4.9[c]	-	-	-	5.75	.92	1.64	.88	-.85[c]	5[c]	-
15. azulene	5.0[c]	-	-	-	8.62	.89	2.17	0	-3.62[c]	8[c]	-
16. 1-4-naphthoquinone	.33	.10	.12	.12	.95	.82	.63	1.60	-.62	.34	.10
17. 4-aminobiphenyl	1.73	.70	.52	.94	.85	.85	1.13	1.27	.88	1.37	.54
18. fluoranthene	8.59	1.82	2.89	2.68	6.18	2.27	1.19	4.48	2.41	7.65	1.42
19. caproic acid	8.1[c]	-	-	-	0[c]	-	-	-	8.1[c]	4[c]	-
Average for compounds with > 50% recovery	8.15	1.60	2.46	2.13	7.67	1.14	1.99	1.56	.13	7.73	.95

[a] Component of standard deviation for variability within a laboratory.

[b] Component of standard deviation for variability between laboratories.

[c] This number is not used for further calculations. The number is not an outlier, but rather is a number that is based on only a few measurements.

Table 4. GC-MS Results Obtained on SRC-II Vacuum Still Bottom Leachates.

	ASTM Method A Leachates			EPA Method EP Leachates		
Laboratory	NBS[a]	Ames	Argonne[a]	NBS[a]	Ames	Argonne[a]
Compound (μg/ℓ)						
phenol	6.68	7	39.7	1.09	5	3.6
o-cresol	1.63	1	2.1	.175	1	.8
naphthalene	.38	.6	.33	.203	.2	.38
quinoline	.39	.1	.34	-	.2	-
1-4-naphthoquinone	.15	-[b]	-	.078	-	-
phenanthrene	.057	-	-	.046	-	-
carbazole	.76	1.8	1.14	.460	.5	1.04
fluoranthrene	.016	-	-	.023	-	-
2-picoline	.24	-	-	-	-	-
dibenzothiophene	.021	-	-	-	-	-
n-tetradecane	-	.1	-	-	-	-

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[a] Average of duplicate GC-MS measurements.

[b] Not detected, and not used in calculations.

Table 5. Statistical Analysis of GC-MS SRC-II Vacuum Still Bottom Results.

	ASTM Method A				EPA Method EP						
Compound ($\mu g/\ell$)	Average	Std. Error	Std. Deviation[a]	%CV[b]	Average	Std. Error	Std. Deviation[a]	%CV[b]	Average A-EP	Std. Dev. A-EP	Observed Student t
phenol	17.79	10.95	18.97	107	3.23	1.14	1.98	61	+14.56	11.01	+1.32
o-cresol	1.58	.32	.55	35	.66	.25	.43	65	+ .92	.41	+2.24
naphthalene	.44	.08	.14	32	.26	.06	.10	39	+ .18	.09	+2.00
quinoline	.28	.09	.16	57	.2	-	-	-	+ .08	?	+
1-4-naphthoquinone	.15	-	-	-	.078	-	-	-	+ .072	?	+
phenanthrene	.057	-	-	-	.046	-	-	-	+ .011	?	+
carbazole	1.23	.30	.53	43	.67	.19	.32	48	+ .56	.36	+1.56
fluoranthrene	.016	-	-	-	.023	-	-	-	- .007	?	-
			Avg. CV = 55%				Avg. CV = 53%				

[a] Std. deviation of a single laboratory result.

[b] Percent coefficient of variation = 100 x standard deviation/average.

Leach Test Analysis on California Soil Test Material

A sample of a sediment material which had been spiked with six chlorinated pesticides was submitted for analysis by the California State Department of Health Services, Berkeley, California. Three 5.00 g samples were Soxhlet extracted with 300 mL of a 1:1 mixture of hexane (distilled in glass) and acetone (distilled in glass). Prior to extraction, 3 mL of aqueous 0.2 mol/L NH_4Cl were added to the sediment to ensure complete sample wetting. Also, 9.74 μg of pentachlorobenzene (Cl_5Bz) and 10.38 μg of 2,2'4,4',5,'-hexachlorobiphenyl (Cl_6PCB) in 1 mL of hexane were added to each sample to serve as internal standards. Two solutions containing known amounts of each analyte and internal standards were also Soxhlet extracted for determination of analysis response factors.

All samples were Soxhlet extracted for 18 hours, after which the unconcentrated extracts were analyzed by gas chromatography (GC). The GC conditions employed for the analysis are summarized in table 1.

Duplicate analysis of the calibration solutions yielded the gram response factors presented in table 2. These values were subsequently used in the internal standard calculations for the sediment extracts. Independent calculations of the six analyte concentrations were made using each of the IS compounds. The three sample extracts were analyzed at least in triplicate, and the results are exhibited in table 3.

Sediment samples were also Soxhlet extracted with hexane alone. These extracts, when analyzed, yielded results approximately 50 percent lower than the spike amount while showing a 15-30 percent intersample standard deviation. These results led us to believe that hexane was not an efficient extraction solvent, and resulted in the second set of analyses with hexane/acetone as the extraction solvent.

Table 1. Gas Chromatographic Parameters.

Instrument:	Varian 3700
Column:	30 m x .25 mm SE-52 WCOT
Carrier:	Helium, 24 psig
Program:	150 °C for 3 minutes; 8 °C/minute to 270 °C; hold 3 minutes
Injector:	J&W splitter, split mode
Split Ratio:	20:1
Detector:	Electron capture, Ni^{63} constant current
Detector Flush:	Nitrogen at 30 mL/minute
Injector Temperature:	300 °C
Detector Temperature:	300 °C
Sample Size:	1.5 μL
Electrometer:	x1
Integrator:	Hewlett Packard 3388

Table 2

Compound	Relative Gram Response Factor
Lindane	0.920
Heptachlor	0.793
Aldrin	0.892
Heptachlor Epoxide	0.828
Dieldrin	0.795
p,p'-DDT	0.602
Pentachlorobenzene	1.00
2,2',3,3',4,4'-Hexachlorobiphenyl	0.577

Table 3

Sample Number	IS 1 Cl_5Bz		Lindane		Heptachlor		Aldrin		Heptachlor Epoxide		Dieldrin		IS 2 Cl_6PCB		p,p'-DDT	
	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2	IS 1	IS 2
1-1	--	2.01	7.49	7.73	3.90	3.99	3.03	3.13	7.30	7.52	1.62	1.67	2.02	--	3.81	3.93
1-2	--	1.95	7.51	7.61	3.99	4.09	3.23	3.23	7.34	7.35	1.63	1.63	2.07	--	3.83	3.83
1-3	--	1.95	7.63	7.68	4.09	4.09	3.13	3.14	7.34	7.39	1.66	1.67	2.06	--	3.94	3.96
1-4	--	1.97	7.63	7.73	4.04	4.09	3.05	3.09	7.38	7.47	1.66	1.67	2.05	--	4.26	4.31
2-1	--	1.98	7.71	7.81	3.99	4.18	3.16	3.20	7.36	7.49	1.65	1.67	2.05	--	3.84	3.90
2-2	--	1.88	7.54	7.29	4.18	3.99	3.09	2.99	7.26	7.02	1.61	1.55	2.15	--	3.88	3.75
2-3	--	1.99	7.71	7.87	4.09	4.18	3.08	3.14	7.52	7.67	1.63	1.67	2.03	--	3.90	3.99
3-1	--	1.86	7.62	7.28	4.09	3.90	3.00	2.86	7.35	7.02	1.63	1.55	2.17	--	4.35	4.16
3-2	--	1.90	7.68	7.49	4.18	4.09	3.02	2.95	7.40	7.22	1.64	1.60	2.13	--	4.15	4.05
3-3	--	2.00	7.72	7.92	4.18	4.28	3.01	3.09	7.48	7.67	1.69	1.73	2.03	-	4.14	4.24
mean (μg/g)		1.95	7.63		4.08		3.08		7.37		1.64		2.07		4.01	
σ		.05	.16		.10		.10		.17		.04		.05		.18	
percent σ		3%	2%		2%		3%		2%		2%		2%		4%	
amount added		1.95											2.08			
spike amount			8		6		3		8		1.4				4	

Multielement Analysis of Oils and Hazardous Waste Leachates Using the Inductively Coupled Plasma Technique

R. L. Watters, Jr.

The inductively coupled plasma (ICP) technique has been applied to the simultaneous multielement analysis of oil samples and leachates of hazardous waste materials. This effort involved three principal developments:

1) The design and construction of a high resolution direct reading spectrometer system.

2) The application of a sealed-tube dissolution procedure to the analysis of oil matrices.

3) The development of on-line data analysis software to identify sources of variability in homogeneity assessment and high-accuracy analysis of oil matrices and hazardous waste leachates.

The spectrometer system consists of two Czerny-Turner spectrometers which are simultaneously illuminated by the plasma torch and associated transfer optics. Each spectrometer can accept a photographic plate or multiple slits in the focal plane. A high-resolution grating can also be installed in each to minimize spectral overlap. Using this facility, the best spectral lines can be chosen and exit slits can be positioned for multielement analysis. The spectrometer system was set up in this way to determine simultaneously nine elements in the hazardous waste leachates. Other elements are determined on an individual basis using one spectrometer in the monochromator mode. Leachates are routinely analyzed for a total of eleven elements using the ICP.

Application of the ICP technique to a wide variety of matrices requires that procedures be developed for both aqueous and organic samples. Aqueous samples can be introduced into the plasma by various types of nebulizers, but organic samples can present unique sample introduction problems. The direct nebulization of oil samples diluted in an organic solvent has been used with the ICP technique. However, if the samples are of widely varying viscosities, or if they contain particulate matter, a digestion procedure is required. Furthermore, pure element standards are more readily prepared in aqueous solution than in organic solvents. The approach involves sample preparation procedures which reduce the amount of nonrandom nebulizer variability. It has been found that when samples of an organic matrix are wet ashed using perchloric acid, the resulting solutions cause appreciable nebulizer pressure drift ($\sim$1 psi). During simultaneous multielement analysis, some element net intensities exhibit corresponding drift. The degree of intensity drift for a given element depends on its optimum observation point in the plasma flame relative to the compromise observation point chosen for all elements. An alternate sample digestion procedure has been used for the ICP certification analysis of SRM 1084 and 1085, Wear Metals in Oil. Ten elements were determined in aqueous solutions of the two materials following a sealed tube dissolution using hydrochloric and nitric acids. The procedure was first described by Carius in 1869 [1] and has since been modified to cover a variety of applications [2-5]. In this particular case, up to 0.5 g of oil can be digested with the resulting solution containing two percent by volume nitric acid. Long-term nebulization exhibits no detectable pressure drift.

Once an analysis is performed, an approach to isolating the variability associated with original sample batches is employed using on-line data analysis of variance (ANOVA) software. The ICP instrument minicomputer logs all data in 512 byte records that cannot be accessed by ASCII editors or data analysis packages. The output subroutine of a report writing program was modified to write sample identification numbers and associated analytical data into a separate ASCII file. This file can be transferred to the NBS main computer for analysis by the OMNITAB software or to the NBS storeroom microcomputer for analysis by BASIC 80 software. For SRM homogeneity studies, the file is transferred to the microcomputer for an analysis of variance of hierarchic data with three sources of variation. Estimates for variance in SRM bottles, sample preparation and instrument drift, and instrument integrations can be calculated in a total of five minutes after reading the data from the minicomputer disc. An average value for each SRM bottle and the standard ANOVA table were printed on one page for each element determined. For application to leachate analysis, the data is transferred to the NBS central computer fora one-way analysis using OMNITAB. This routine separates the variance due to the leaching process from the variance of the instrumental analysis. When an estimate of variance among leachates of a common waste source is desired, the two-way analysis of variance is performed by OMNITAB.

References

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Polymer Modified Electrodes: Chemically Modified Electrode Detectors for Halogenated Hydrocarbons

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and

William T. Yap

Chemically modified electrode sensors may allow the selective and sensitive detection of organohalide compounds. Thus, such sensors might be extremely useful for rapid but accurate analysis of waste sites or for monitoring of existing or abandoned sites. The decision to utilize polymer film electrodes was made with the following advantages in mind: large chemical and physical stability of polymer films, a great number of sites to immobilize the catalyst of choice, and facile electron transfer.

Scanning electron micrographs of the originally proposed polyphenylene oxide polymer films showed a very irregular and inhomogeneous polymer surface. This prompted the search for other polymer films to attach to electrode surfaces. We have followed two routes of investigation: electrochemical initiated polymerization of vinyl catalyst monomer and spin-dip coating of polymer films. In the first route, the immobilization scheme involves anionic polymerization through a chelated vinyl group. In the second technique, the polymer films formed are of two types: either electrostatic binding of a charged catalyst molecule or pendant chelating groups (i.e., pyridine) are the immobilization agents. This second technique offers a great deal of flexibility and freedom to optimize experimental conditions.

The catalytic system utilizing vinyl_polymerization was based on $[\mathrm{RuII(Bipy)_2\,(4\text{-}vinylpyridine)}] \cdot 2PF_6$. With the following reactions, a very strong luminescence is observed:

$$(1)\quad Ru^{II}L \underset{+e^-}{\overset{-e^-}{\rightleftharpoons}} Ru^{III}L$$

$$(2)\quad Ru^{III}L + RCO_2^- \longrightarrow Ru^{II}L + R + CO_2^{\dot{-}}$$

$$(3)\quad Ru^{II}L + CO_2^{\dot{-}} \longrightarrow Ru^{II}L^- + CO_2$$

$$(4)\quad Ru^{III}L + Ru^{II}L^{\dot{-}} \longrightarrow 2Ru^{II}L + h\nu$$

Inner Layers of Film	Outer Layers of Film

where, $L \equiv (\mathrm{Biphy})_2(4\text{-vinylpyridine})$ and RCO_2^- was 50 mM $Na_2C_2O_4$. We have demonstrated the catalytic oxidation of organic carboxylates; further work is being pursued in the catalytic reduction of organohalides.

We have spin-dip coated electrodes with polyvinyl pyridine. To this modified electrode we have immobilized NiII Schiff-base complexes. These electrodes have shown reversible NiII/NiI electrochemical behavior. With subsequent exposure of these electrodes to 1,2-dibromoethane, a catalytic reduction wave was observed. Further work is being pursued in the practical implementation of this system as an electrochemical detector.

Recently, we have utilized a cation exchange polymer sensor (Nafion TM) to incorporate organic cation catalyst molecules. Examples of the cation catalyst molecules we have investigated are methyl viologen and methylene blue. These organic cations show reversible electrochemical behavior and are under further characterization.

Future work will be focused on investigating the effects of polymer film cross-linking on film stability and electron transfer. Other work will attempt to utilize the available photochemistry of the excited state of $RuII(Bpy)_3$ for transport studies. Finally, theoretical modifying and experimental work will be aimed at developing mechanisms of electron transport and migration of ions within the film.

Combined Liquid Chromatography/Mass Spectrometry

Richard G. Christensen

Liquid chromatography (LC) can be used for the separation of many nonvolatile and polar molecules that are not amenable to gas chromatography (GC) and can handle many samples in matrices not amenable to gas chromatography, such as water or heavy oil. Therefore, the coupling of a mass spectrometer (MS), which is a very specific detector, to a liquid chromatograph has generated a great deal of interest. If this could be accomplished, many of the advantages of GC/MS could be realized with LC separation. Numerous publications on LC/MS have appeared, and two methods have been used in commercial instruments. However, neither of these types of instruments has been used for quantitative analysis.

We have constructed a unique LC/MS interface that operates by removing most of the excess solvent from the LC effluent stream as it flows down a heated wire. The residual concentrated solution is drawn into the vacuum of a mass spectrometer and volatilized into the ion source. This interface and some applications of normal-phase chromatography have been described in Christensen et al., Anal. Chem. 53, 171 (1981).

A large fraction of analytical LC is now performed using reversed-phase chromatography. It is, therefore, desirable to have an LC/MS interface which will accommodate the aqueous solutions used in that mode. An interface with an ultrasonically vibrating probe tip has been developed to disperse these solutions into a vacuum. An early model, fitted with a poly(vinylidene fluoride) film, which served as a seat for the miniature needle valve, proved to have a short lifetime. Therefore, a new valve was designed with a seat formed by swaging the nickel capillary tube down upon the tapered tungsten wire. The resulting valve was durable enough to survive several months of intermittent operation.

For moderately volatile molecules, the system was sufficiently stable to permit quantitation, but less volatile compounds showed large, rapid variations in sensitivity. We believe that this difficulty is linked to the size of the droplets generated. The droplets from this probe are estimated to be about 25 mm in diameter. Other workers whose interfaces spray liquid at higher pressures report that the droplet sizes achieved are smaller, e.g., 5 mm. Special probes were designed and built with the aim of obtaining smaller drops through larger amplitude of vibration or with higher frequency of vibration, but in neither case was the desired result obtained.

Among the applications accomplished was the measurement of the levels of various aliphatic acids in a shale oil process water. The difficulty of this analysis can be appreciated from examples of other methods used: extraction and GC/MS with internal standards; steam distillation followed by extraction and GC; ion exchange stripping followed by LC with conductivity detector; extraction and derivatization followed by GC. These obviously require considerable time and effort. The LC/MS aliphatic analyses were performed by simply injecting the aliphatic acid sample directly into the LC with no pretreatment. A C-18 reversed-phase column was used with water/methanol as solvent at 1 mL/minute. The responses of the samples were compared with external standards.

A table of the results with the GC/MS results included for comparison is shown below.

Concentration of Aliphatic Acids (μg/g) in a Shale Oil

Process Water

(Mean ± Standard Deviation of a Single Measurement)

Acid	LC/MS	GC/MS[a]
Butanoic Acids	91 ± 10[b]	49.6 ± 7.6
Pentanoic Acids	84 ± 10	71.9 ± 8.9
Hexanoic Acids	87 ± 13	87.8 ± 4.4
Heptanoic Acids	136	149.5 ± 9.2

[a] Specific for n-acids.

[b] Includes n-butanoic and 2-methylpropanoic acids.

Development of a Temperature Stabilization System for a D.C. Plasma/Echelle Spectrometer

C. G. Blundell and M. S. Epstein

A major source of error in the analytical application of direct-current plasma/Echelle spectrometry is thermally-induced wavelength drift. This drift is a direct consequence of instrument design, since the high temperature (6000 °C) plasma source is directly mounted on the same aluminum baseplate as the spectrometer optics. During plasma operation, a large thermal gradient is established across the spectrometer which results in a drift of wavelength and consequently a drift in intensity throughput. System equilibration can take as long as eight hours with intensity drift of 20 percent per hour. Since the drift is not linear and difficult to model, a system was developed to eliminate the drift, rather than try to correct for it.

The temperature stabilization system consists of several thermistor probes which are placed at critical points in the spectrometer, such as at the grating/prism mount. These probes are used as sensors for a temperature controller which regulates a heating tape surrounding the spectrometer baseplate to maintain a constant temperature (± .05 °C) at the probe position.

The system has significantly improved the spectrometer stability and thus the precision with which measurements can be made using the dc plasma. It has proved most useful in critical simultaneous multielement applications, such as the determination of nine elements in solid-waste leachates and 12 elements in simulated nuclear waste leachates. In the latter case, the amount of information that could be derived from the analytical results was directly proportional to the measurement precision. Further improvements in measurement precision will only be obtained by the modification of sample transport techniques or by the application of ratio (internal standardization) methods. Investigations in these areas are proceeding.

Development of a Quality Assurance Sludge Material for Hazardous Waste Analysis

L. Hilpert

The NBS Organic Analytical Research Division has been working with the EPA to develop methods and reference materials for the analysis of toxic organic constituents in hazardous wastes. The first of the organic quality assurance materials consists of an industrial sludge which was diluted and fortified with eleven priority pollutant organic compounds. The levels of the eleven toxic organic compounds in the sludge were in the range of 1-40 parts per million. Quantitative measurements of the eleven organic compounds added to the sludge were made by combined gas chromatography/mass spectrometry. The use of high resolution fused silica capillary columns coupled directly to the ion source of the mass spectrometer allowed separation of the compounds of interest from nonanalyte interferences in the sludge. Selected ion monitoring detection provided additional selectivity. The results of these measurements enabled us to determine the accuracy and precision attainable in the quantitative determinations of individual organic compounds in a complex matrix, such as an industrial sludge. The use of this material will allow the EPA to monitor the performance of laboratories involved in the analysis of hazardous wastes.

APPENDIX VII. THE WASTE-ENVIRONMENT-TECHNOLOGY MODEL:

A BRIEF EVALUATION AND ASSESSMENT

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FOREWORD

The evaluation and assessment which follows utilizes some of the results of hazard scoring reported by the developers of a model known as the Waste-Environment-Technology Model. These results have been used to suggest certain statistical inferences for assessing degree of hazard posed by certain chemicals. Thus, the results of the hazard scoring and its underlying foundation were assumed satisfactory for use in deducing statistical examples. Note that the text is not meant to provide an exhaustive review of the problems associated with the modeling of waste streams, economic trade-offs in dealing with wastes, or determining absolute risks relating to chemicals.

On September 28, 1982, the Science Advisory Board of the U.S. Environmental Protection Agency held a public meeting to discuss the RCRA Risk/Cost Policy Model Project (Phase 2 Report of June 15, 1982) which embodies the commonly referred to Waste-Environment-Technology (W.E.T.) Model. The meeting was convened in order for the Board to make public some of the findings of its review of specific details of the W.E.T. Model. In addition, findings of other representatives, the public, e.g., the Environmental Defense Fund, Congressional Office of Technology Assessment were presented before the Board.

The Board identified and addressed the following major issues:

1) Appropriate applications of the model. The potential utilization of the model in policy and regulatory decisionmaking processes was of particular interest. The Office of Technology Assessment (OTA) suggested that perhaps no model would be appropriate to this task.

2) Data requirements. All reviewers (Board members, SAB constituents, representatives of the public/private sectors) were deeply concerned about the availability--or lack thereof--of reliable data base from which modeling decisions and conclusions might be drawn.

3) Need for sensitivity analysis. General agreement was reached that sensitivity analysis for the various aspects of the model, i.e., risks, economics, is needed. But a

majority of the reviewers indicated that obtaining a valid sensitivity analysis, given the quality of presently available data, would be very difficult.

4) Differences in types of health as well as environmental risks exist. A desire was expressed for an accurate means to evaluate the severity of hazards, e.g., cancer, as contrasted with a minor irritant.

5) Rationalization of the economic and health related assumptions used in the model. Several reviewers were concerned about the exact algorithm used--and its validity--in order to obtain specific results for a given waste stream.

6) Desire for expansion of the scope of the model. Some reviewers were concerned that the number of waste streams considered-- 83 representing about 25 percent of the waste generated--was insufficient. Other reviewers suggested that the data were poor in any case. Still, most agreed that a broader base would be useful.

A majority on the Board concluded that the present version of the W.E.T. Model is "a good first step" in approaching an exceedingly difficult set of problems. For example, the concept of using an order-of-magnitude scoring system in light of the available data was acceptable although questions about some of the risk assumptions were raised. Further study of the modeling problem would seem to be in order. The key issue is the requirement for critically evaluated data in all of the areas encompassed by a model of this type, e.g., health effects, threshold effects, mobility of chemicals in the environment, and many others.

The text that follows does not deal with these issues, but rather with the use of some results of the model. The basis of hazard scoring of the model is presented; the results of this scoring system have been used to suggest statistical inferences concerning any method purporting to be a vehicle for assessing degree of hazard posed by certain chemicals. Finally, a few general comments on the use of the W.E.T. hazard scoring system are presented as well as some very broad economic implications of adoption of this scoring system to parties-of-interest such as generators or treaters of waste.

The W.E.T. Matrix

In order to deal with the practical aspects of managing hazardous wastes, the Waste-Environment-Technology (W.E.T.) Model was developed for the United States Environmental Protection Agency (EPA) in order to derive, test and apply a degree-of-hazard framework for regulating hazardous waste facilities. The Model was prepared by three firms working under contract to EPA:

ICF Incorporated
SCS Engineers
Clement Associates.

According to these firms:

"The risk posed by a waste stream is related to a number of factors, the most important of which are:

- the inherent hazard and physical properties of the waste stream, which depend primarily on the nature of the waste stream and its chemical constituents;
- the quantity of the chemicals released and the medium into which they are released, which depend on the size and nature of the waste stream, and on the technology;
- the persistence of the chemicals, the rate of their dispersion, and other factors governing exposure, which depend primarily on the nature of the waste stream and on the environment;
- the size of the human population potentially exposed to the chemicals, which depends primarily on the environment; and
- the presence of nonhuman systems that can be adversely affected, such as sensitive ecosystems or valuable resources, which depend primarily on the environment.

Thus, risk involves all three components of the W.E.T. matrix and the risk scoring system accounts for all three.

"In this phase of developing the model, we (the model builders) make four major decisions that greatly simplify the problem and allow us to test our approach, while also preserving the factors that will usually dominate any comparison of risk:

1) The scoring system is an index of risks to human health.

2) The scoring system combines all types of health risk into a single numerical score; a second score characterizes the range of uncertainty.

3) The scoring system characterizes the risks of waste streams by their individual chemical constituents.

4) The scoring system assigns scores to the nearest order of magnitude.

"There are two general problems in scoring risks to health posed by hazardous wastes. First, most waste streams are complex mixtures, and many are poorly characterized. Second, even if adequate information were available on the composition of the wastes, for most chemicals, there is insufficient information on inherent hazard and environmental behavior to permit precise estimates of risks. For these reasons, scoring for risks to health is subject to large uncertainties and in many cases depends on scientific judgment. The scoring scheme we developed does, however, base application of scientific judgment on a formal scientific underpinning. By providing rigorous definitions of the factors to be scored and by specifying numerical equivalents for the scoring categories, it is possible to assign fairly precise scores to a number of well-studied chemicals. These scores can then guide the assignment of scores to less well-studied chemicals and to mixtures...

"Many factors contribute to the risk posed by a W.E.T.--the number of people potentially affected, the average intake per person per day, the probability of response per unit of intake, and the severity of response--and all are considered independently. These factors are defined so that they interact multiplicatively in contributing to the overall risk. We assign scores to these factors on an approximate logarithmic scale and then sum them to provide a measure of overall risk:

1) log (risk) = constant + (sum of scores)

The constant is unspecified; thus, the system initially provides a measure only of relative risks.

"We define the overall risk presented by disposing of a waste as the expected or most likely number of people affected. Since some chemicals persist essentially forever after release into the environment, the scoring system also assesses the risk of disposing of the waste indefinitely. The system allows for the option of discounting risks that do not occur until 30 or more years in the future, but does not now discount risks.

"We define the major factors as follows:

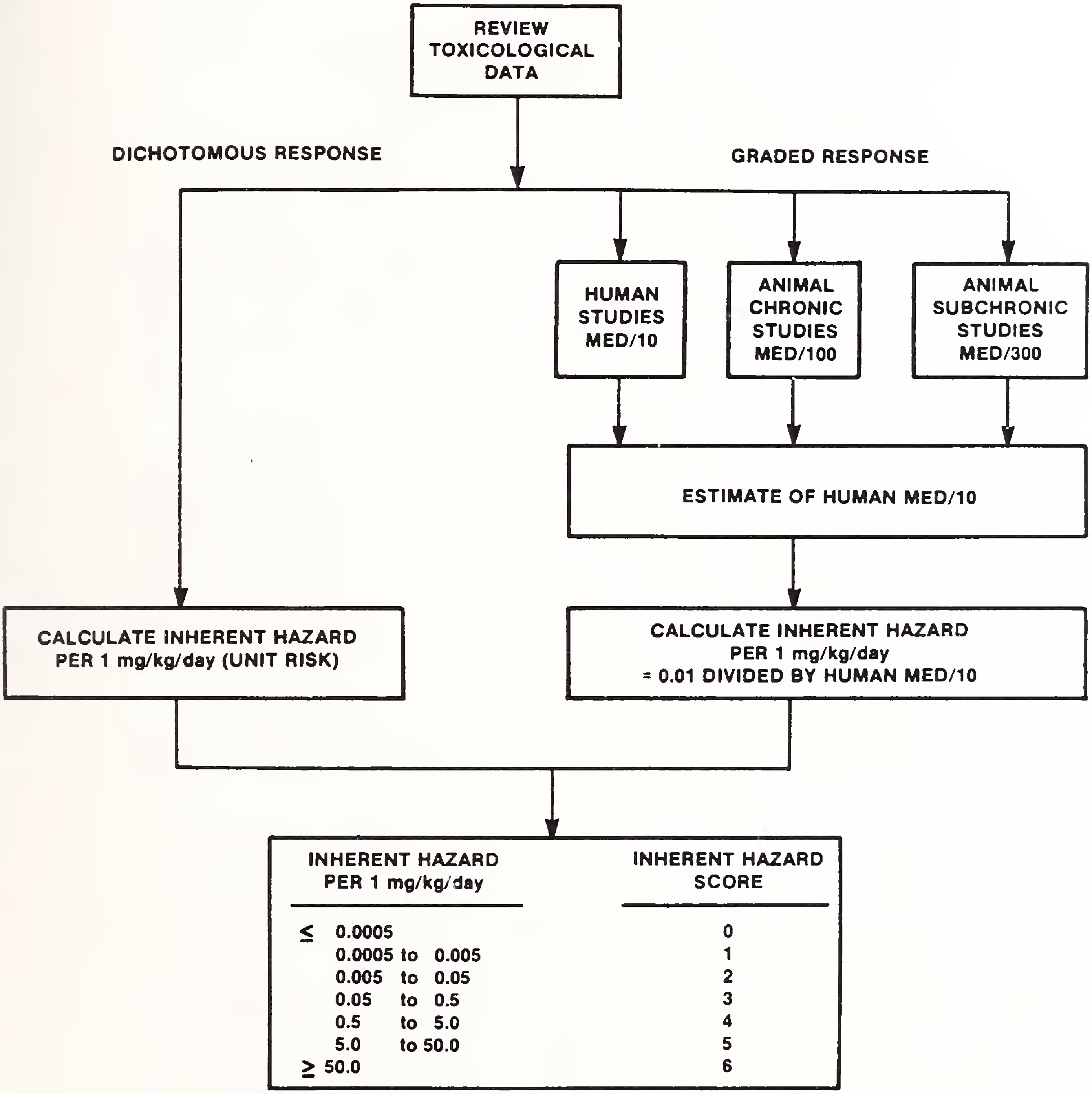
2) Overall risk (expected number of people affected) = $P \bullet E \bullet H$, where:

P = Population at risk (number)
E = Exposure (average intake per person per day)
H = Inherent hazard (probability of response per unit intake)

"As presented above, the overall risk is equated with the number of people affected, irrespective of the type of effect. In practice, some types of effects are generally regarded as more "serious" than others. To take account of this, the scoring system could be generalized by adding a (multiplicative) index of severity, which would approach a value of 1 for the most "serious" effects, but might come close to a value of 0 for effects judged to be least serious. The assignment of indices of severity involves value judgments. Table 1 provides a flow chart for scoring inherent hazard.

TABLE 1

FLOW CHART FOR SCORING INHERENT HAZARD


REVIEW TOXICOLOGICAL DATA
DICHOTOMOUS RESPONSE
GRADED RESPONSE
HUMAN STUDIES MED/10
ANIMAL CHRONIC STUDIES MED/100
ANIMAL SUBCHRONIC STUDIES MED/300
ESTIMATE OF HUMAN MED/10
CALCULATE INHERENT HAZARD PER 1 mg/kg/day (UNIT RISK)
CALCULATE INHERENT HAZARD PER 1 mg/kg/day = 0.01 DIVIDED BY HUMAN MED/10

INHERENT HAZARD PER 1 mg/kg/day	INHERENT HAZARD SCORE
≤ 0.0005	0
0.0005 to 0.005	1
0.005 to 0.05	2
0.05 to 0.5	3
0.5 to 5.0	4
5.0 to 50.0	5
≥ 50.0	6

[MED = Minimum Effective Dose, i.e., the lowest dose which produces a clearly observable effect]

"The submodel for exposure is:

3) Exposure (average intake per person per day) = $Q \bullet F \bullet D_i \bullet I_n \bullet A$

where:
Q = Quantity of material handled
F = Expected fraction released
D_i = Dispersion factor (concentration in the ambient environment per unit of release)
I_n = Intake factor (breathing rate, consumption of drinking water, and so on)
A = Absorption coefficient

The last three subfactors vary considerably from one environmental medium to another. Hence, it is necessary to assign and sum exposure scores separately for each medium. The highest of the scores for the various media is essentially the measure of risk because of the logarithmic scale (that is, any score less than the highest is at most one-tenth as large and is not considered when rounding).

"In our model, the overall risk depends linearly on the quantity of material that is released. Unlike the other factors, quantity is not an inherent property of the W.E.T. It can be reduced, at increased cost, by improving the level of technology or by dispersing the waste stream to other facilities. As noted earlier, one of the objectives of the analysis is to explore the trade-offs between cost and risk resulting from such changes. Hence, the quantity released is not a consideration in the risk scoring system. The final risk score is an estimate of the logarithm of the overall risk per unit of material released.

Because uncertainties are large in many cases, the system provides for assigning a measure of uncertainty to scores for both inherent hazard and exposure. Uncertainties arise from four major sources:

- lack of information (for example, on inherent hazard or environmental behavior);
- site-to-site variability within a W.E.T. (such as quantities of materials released or hydrologic conditions);
- variability related solely to the environment (for instance, differences in susceptibility within the population); and
- chance occurrence (such as probability of leakage).

"Although these types of uncertainties are formally distinct, we assume that they can be combined meaningfully into a single measure of probability. We assume further that the distribution of probabilities (in this broad sense) for each factor is about lognormal. Then the logarithmic score on each factor can be characterized by a single expected value (mean) and variance, and the variances can be combined by standard methods to yield a single measure of uncertainty in the overall risk. These overall measures of uncertainty are, in practice, similar for many waste streams; thus, they contribute little to the process of ranking. We found some cases, however, where we judged the uncertainty in the risk scores to be substantially larger than average. The system provides for identifying these cases and for carrying estimates of uncertainty through the analysis.

"A number of exposure factors (number exposed, intake factor, absorption coefficient) are measured on numerical scales; thus, assignment of logarithmic scores is relatively straightforward. The most difficult factors to score are inherent hazard and environmental transport."

The model builders proceeded to score 140 substances largely based on the EPA list of 129 priority pollutants. Appendix I provides a copy of these results; Appendix II contains the uncertainty scores suggested by the W.E.T. model builders. Figures 1 - 4 show the distribution of inherent hazard score, H, and the total score, $W \equiv H + E$, for air, surface water, and ground water paths. Note that "E" is the exposure adjustment for each of these three media.

The cumulative distribution of the population represented by the sample of 140 substances can be predicted by means of a confidence interval deduced by the methods of non-parametric statistics. This prediction is possible since figures 1 - 4 indicate the cumulative distribution of the sample. With a sample size of $Q = 140$, we may be 99 percent certain that the maximum deviation between the cumulative distributions of the population and of the sample is equal to or less than $1.63/(Q)^{\frac{1}{2}}$. For $Q = 140$, then this deviation is ± 13.8 percent. In other words, the entire population represented by the 140 substances can be represented by histograms within ± 14 percent of those shown in figures 1 - 4. For example, figures 1 - 4 indicate that 58 percent of the sample of 140 substances lie in the range $0 \leq W \leq 7$. The statistical inference is that 50 to 66 percent of the entire population represented by the 140 substances lies in the range $0 \leq W \leq 7$.

Some relationship between actual risk and these W.E.T. matrix scores must exist. Furthermore, measurement uncertainties involving the concentrations reported for various constituents must play some role in setting boundaries on any risk evaluation system such as the W.E.T. scheme. Then, too, the response of the W.E.T. scoring scheme to changes in concentration of constituents which might be escaping needs to be taken into account. In what follows, each of these issues will be dealt with; in addition, the statistical inference of utilizing the product of the population exposed, N, with the inherent hazard and exposure to express risk will be assessed.

Risk-Concentration Relationships

The dose experienced by some population or ecosystem as a result of hazardous waste operations or storage--via any path of escape from a facility--needs to be related to observed instances of harm or the possibility of harm at some undefined future date. In all of the following discussion, assume that the exposure or dose is meant to occur as a result of a hazardous waste facility. Further, assume that the dose can be measured accurately and that the sampling procedure is statistically valid.

Toxicity testing for incidence of adverse effects in animals and humans as related to exposure or dosage always results in a sigmoidal or S-shaped dose-risk curve (see fig. 5). Under the terms of the assumptions, zero dose means zero risk. But, the cumulative probability of risk as a function of very low doses or levels of exposure is nearly impossible to measure or to predict theoretically as indicated in figure 5.

For example, the question of a dose threshold arises immediately. If a threshold exists, then there are exposure levels of certain substances, e.g., carcinogens, such that no matter how many animals are exposed, none will exhibit cancerous tumors. Leading authorities have stated flatly that resolution of the threshold question is not possible given the current state of scientific knowledge--even in a large-scale experiment involving several thousand animals per exposure level.

Next, if no threshold is assumed, i.e., one molecule of the substance has some finite--even if vanishingly small--probability of causing harm, the relationship of the exposure to risk level must be correctly known as the exposure approaches zero. Here two other uncertainties intervene: 1) What is the minimum detectable limit of concentration of the emanations from the site in the various paths and media via which the emanations can travel? 2) Is there any valid mathematical statistical model for extrapolating from detectable levels to zero exposure?

Minimum detection limits for certain organic and inorganic species have been reported in the so-called part-per-billion range. Such determinations--especially in heterogeneous mixtures and media--have wide ranges of uncertainty (large confidence intervals) and are exceedingly difficult to perform. (Note that one part-per-billion corresponds to about 600 trillion molecules of the substance under test.) Accurate measurement at low exposure levels is likely to be difficult to obtain and is likely to be very expensive.

Consider now models for extrapolating from measurable exposure data to the risk at lower exposures. In one experiment, some 24,000 female mice were subjected to a known bladder and liver carcinogen in order to study dose responses down to a one-percent tumor incidence, i.e., the concentration of the carcinogen which would cause one mouse in 100 to develop liver or bladder tumors.

Results of these tests were not especially enlightening. For example, a linear extrapolation and a "Weibull model" which is a statistical probability distribution having a finite starting point for estimating life distributions as a function of exposure, were applied to the data.

For a one in a million risk ($P = 10^{-6}$) of liver cancer in the mice, an 0.045 part-per-billion dose of the carcinogen was predicted by the linear model; the Weibull model predicted a 4.5 part-per-billion dose for $P = 10^{-6}$ or an exposure of 100 times greater for the same risk.

The EPA Carcinogen Assessment Group has stated that:

> "There is no really solid scientific basis for any mathematical extrapolation model which relates carcinogen exposure to cancer risks at the extremely low level of concentration that must be dealt with in evaluating the environmental hazard."

With respect to the prediction of "time-to-tumor" data, there is no agreement between available models. Results are different, and certainty of prediction appears impossible at present.

As stated by the Congressional Office of Technology Assessment:

> "The accuracy of the relation between exposure and incidence (of adverse effects) is always limited. Practical restraints on the number of animals that can be tested means that the data are always subject to significant experimental error; it also means that only relatively high incidences, almost always greater than 10 percent, can be measured in the experiments. There is also no agreement about which mathematical models best extrapolate from the exposure levels measured in studies to those encountered in the environment. Linear models, which assume that incidence is proportional to exposure at low exposure levels, are used by Federal agencies."

Note that use of a linear model tends to be "conservative," i.e., it predicts a higher cumulative probability for harm at lower exposure levels. As a practical matter, there is often no alternative to the linear model.

Apparently, there is no unambiguous valid means to directly relate the probability for harm to a measured exposure level at low exposure levels. This situation poses another challenge:

- Estimation of the potential population who might be exposed to effects from the site and determination of the proportion of this population who might suffer harm as a result of the existence of the site.

The proportion of the population in the exposure area who would be unaffected if the site did not exist can be found via application of the theory of competing risks. For example, a person in the exposure area may be ill for reasons entirely separate from the existence of the site. The elements of the problem may be stated as follows:

Given:

y = Number of population in exposure area now who are not ill

u = Number of population in exposure area showing adverse effects which might be attributed to chemical exposure via some path

z = Number of population in exposure area who would be unaffected if dump did not exist

Required:

"z" in terms of "y" and "u"

Steps:

Let dz be the decrement of "z" in a small time.

Let dy be the decrement of "y" in the same small time.

If "z" individuals were subject to adverse effects due to chemicals, then

$$dz = \frac{z}{y}\,dy$$

But: We must subtract from this value of dz the decrement arising from suffering of adverse effects caused from exposure to chemicals via some path. We must make such a subtraction since the "z" individuals are--by hypothesis of this problem--not liable. This decrement is

$$(z/y)du.$$

Therefore,

$$dz = \frac{z}{y}\,dy + \frac{z}{y}\,du$$

(We utilize +(z/y)du and not -(z/y)du since "z" and "y" decrease while "u increases.)

Rearranging:

$$\frac{dz}{z} = \frac{dy}{y} + \frac{du}{y} \text{ , so}$$

$$\log z = \log y + \int \frac{du}{y} \text{ , and}$$

$$z = ye \int \frac{du}{y}$$

At some time "x" incremented via dt, Equation (6) can be rewritten as

$$z = y \exp \left[\int_{o}^{x} \frac{1}{y} \frac{du}{dt} dt\right]$$

The right-hand side of this expression can--in principle--be estimated. But, in practice, obtaining the necessary data in unambiguous form and over a period of time represents a formidable, if not impossible, problem in epidemiology. Hence, great uncertainty in identifying members of the exposed population who suffer harm as a result of the hazardous waste site is likely to be the case.

At this point, the chief difficulty for the regulatory process should be clear: How to implement mandates to control possible risks associated with waste disposal in a fair, objective and accountable manner by using rational approaches such as scientific and technical data and cost-benefit analyses. These approaches tend to emphasize economic cost factors, but the concerned portion of the public generally considers that the health and environmental amenities at stake are unmeasurable in economic terms; in fact, most of the public probably wishes "zero exposure" from waste disposal.

If the regulatory process operates utilizing quantitative targets for defining a waste as "hazardous" and if exceedingly low concentrations of substances in the waste must be achieved, costs of control rise rapidly. Obviously, the lower the required concentration, the higher the cost of control. Hence, some balance between these costs and exposure is needed. Once a risk is accepted as real, i.e., worthy of regulatory attention, the stringency of the regulation depends on economic and technical factors to be workable.

One proposed method for taking these factors into account is to classify wastes destined for disposal into categories depending upon the substances, their concentrations and their propensity to move and/or to persist in the environment by any path. Thus, high concentrations of a known carcinogen, which moves rapidly and is persistent, might require a more stringent level of control than lower concentrations of the same substances; a different substance which moved more slowly or was not a known carcinogen might require less control and so on.

In principle, this classification scheme is appealing since only the most objectionable wastes would require the most expensive monitoring and treatment. In practice, immediate difficulties present themselves in how to set the classifications and to administer control over them in a fashion acceptable to the public.

Some of the technical difficulties will be apparent from an examination of table 2 in which two objective and competent groups of scientists attempted to define cancer risk[1] from drinking water containing one part-per-billion (one microgram per liter) of known carcinogens. The table purports to indicate the number of persons per million exposed who are likely to fall victim to cancer from drinking this water. Note that in several cases, a tenfold to hundredfold difference exists between the two estimates. Data taken from table 2 are shown plotted in figures 6 and 7 assuming a linear relationship between concentration and excess cancer risk. These results may be used to link the W.E.T. matrix scoring system with approximate actual hazards.

Examination of the range of inherent hazards, H, per 1 mg/kg/day (1 PPM per day) as shown in table 1 suggests that when H is 4 or more, the inherent hazard exceeds unity, i.e., the hazard, whatever its nature, would seem to be assured to all who were exposed. In addition, values for H of 4 or more appear to be well beyond the range where dose and risk are linear. Linear response ceases when the[2] hazard exceeds 0.1 to 0.15. (See fig. 5.)

Reference to table 2 indicates that if the hazard is in the linear range, i.e.,

4) Hazard = mC_x where

C_x is the concentration of the substance causing hazard, and m is the slope of the linear relation,

then for vinyl chloride with C_x = 1 PPM, "H"* is approximately 0.1 (CAG data) or 0.002 (NAS data). The W.E.T. scheme gives H = 3 for a hazard of 0.1 and H = 1 for a hazard 0.002. The score listed by the model builders is H of 2 for vinyl chloride.**

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[1] $H \approx mC_x$ (with risk H and C_x 1 ppb can calculate m)

[2] expressed as fractional excess tumor incidence with linearity assumed up to D = 1D in figure 5.

* re: vinyl chloride from table 2 (original draft read "m" not "H", it is corrected here).

** See bottom table 1, p. 4.

TABLE 2

Concentration of Drinking Water Contaminants and Calculated Excess Cancer Risk

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	NAS[a] 10^{-6} ug/1[c]	CAG[b] 10^{-6} ug/1[c]
Acrylonitrile	0.77	0.034
Arsenic	ND[d]	0.004
Benzene	ND	3.0
Benzo(a)pyrene	ND	ND
Beryllium	ND	0.02
Bis(2-chloroethyl)ether	0.83	ND
Carbon tetrachloride	9.09	0.086
Chlordane	0.056	0.012
Chloroform	0.59	0.48
DDT	0.083	ND
1,2-Dichloroethane	1.4	1.46
1,1-Dichloroethylene	ND	0.28
Dieldrin	0.004	ND
Ethylenedibromide	0.11	0.0022
ETU	0.46	ND
Heptachlor	0.024	2.4
Hexachlorobutadiene	ND	1.4
Hexachlorobenzene	0.034	ND
N-nitrosodimethylamine	ND	0.0052
Kepone	0.023	ND
Lindane	0.108	ND
PCB	0.32	ND
PCNB	7.14	ND
TCDD	ND	5.0 x 10^{-6}
Tetrachloroethylene	0.71	0.82
Trichloroethylene	9.09	5.8
Vinyl chloride	2.13	106.0

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[a] Standardized to 10^{-8} risks from National Academy of Sciences Drinking Water and Health (266) for consumption of 1 l/water/day.

[b] Recalculated to exclude aquatic food intake from Cancer Assessment Group, Ambient Water Quality Criteria (104). Standardized to 1 l/water/day intake.

[c] Average adult water consumption is 2 l/day.

[d] Not discussed.

SOURCE: Office of Technology Assessment.

If one is interested in the range where inherent hazard and concentration is linear,[≠] the scale of inherent hazard apparently needs to be shifted. Figure 8 shows the inherent hazard scale suggested by the model builders as well as a proposed shift based on the data of table 2. In other words, the distribution of inherent hazard scores determined by the model builders is acceptable but the slope of a linear relationship utilizing these scores can be expressed as:

5) $m \equiv 10^{(W-10)}$ if C_x is in PPB.

Hence, hazard is suggested as

6) Hazard $\approx 10^{(W-10)} C_x$ where

H as inherent hazard from the model

E as "exposure" from the model; presumably the value of "E" accounts for persistence, bioconcentration, mobility, etc.

The proposed shift*** agrees with the H values determined by the model builders within one unit in about two-thirds of the cases where the substances in table 2 have been scored by the model builders and within two units for about 85 percent of such cases. Since the uncertainty in "W" values suggested by the model builders is ± 1.4 to 2.5 units of W (see Appendix II), this agreement is considered satisfactory.

Some Considerations in Evaluating Exposure from a Hazardous Waste Facility

Presumably, any index describing degree of hazard will increase as the danger of environmental and/or health risk increases. Thus, the value of the index must be made to depend, as quantitatively as possible, on the likely fate of various wastes in various environments. The following summarization indicates some relations of physicochemical properties to environmental behavior:

[≠] Region in figure 4, p. 11, as discussed on p. 17.

***$m = 10^{W-10}$ $w = 10 + \log_{10} m$ w is the inherent hazard score
$H = mC_x$ is the inherent hazard per ppm.
NAS (vinyl chloride)
$m = 2.13 \times 10^{-6}$ gives $w = 4.33$ and inherent hazard, $H = mC_x = 2.13 \times 10^{-3}$ for 1 ppm.
CAG (vinyl chloride)
$m = 1.06 \times 10^{-4}$ gives $w = 6.03$ and inherent hazard, $H = mC_x = 1.06 \times 10^{-1}$ for 1 ppm. (1 ppm is used since W.E.T. scheme uses this)

Physical Chemical Data	Related To:
1. Solubility in Water	Leaching, degree of adsorption, mobility in environment
2. Latent Heat of Solution	Adsorption, leaching, vaporization from surfaces
3. Partition Coefficient	Bioaccumulation potential, adsorption by organic matter
4. Hydrolysis	Persistence in environment and biota
5. Ionization	Route and mechanism or adsorption or uptake, persistence, interaction with other molecular species
6. Vapor Pressure	Atmospheric mobility, rate of vaporization

As an example, many compounds which accumulate in the tissues of living organisms have been found to have a low water solubility but a high solubility in non-polar solvents. The partition coefficient of such compounds provides a fair measure of their tendency to accumulate in living organisms. This, coupled with a resistance toward reaction, gives an indication of transmission from one trophic level to another as well as of bio-accumulation. The solvent usually selected is n-octanol since it is convenient to use and resembles the adipose tissue of certain living organisms.

With regard to leaching, the important factors are the water solubility of the hazardous waste mixture, adsorption, soil type and moisture, and percolation velocity. One would expect the amount of chemical carried in the soil to be proportional to the amount of water available to dissolve the specific species; temperature must also play an important role in leaching since it affects solubility.

Assume that there is an existing or proposed land-based site in which possibly hazardous discards have been (or will be) placed. The site can be a pit, pond, lagoon, landfill or land spread, deep-well injection, salt dome or encapsulated (fixed) deposit. Note that abandoned sites can be taken into account as well. In addition, airborne effluents and residuals from an incinerator can be included. Almost certainly, the following general questions will have to be dealt with in some detail:

a) What is present?

This question requires that qualitative analysis for all constituents be carried out. Generators and disposers can, of course, check incoming shipments fairly accurately. In the case of old sites, some means of accurate qualitative analysis sensitive to very low levels of various constituents must be developed. Thus, sampling protocols and relatively rapid identification procedures are needed--which are economically affordable. Clearly, organizations such as ASTM will need to compare sampling protocols, develop and evaluate various test methods and agree on standards of comparison.

b) How much material is present or planned for the site?

Total amounts of potentially hazardous substances will be of interest to any local jurisdiction.

c) How long has the site been in its present location? Are records available?

This information is needed if an appropriate monitoring scheme for emanations from the site is to be developed.

d) What is in the vicinity of the site? Are its boundaries--in three dimensions--well defined?

Paths by which emanations from the site may migrate into ecosystems, e.g., via ground water, surface water, air, soil, etc., must be determined. Population density and land use are also required.

e) Are constituents escaping from the site?

Soil characteristics need to be assessed, e.g., composition, permeability to the constituents at various depths, conductivity, pH and others. In the case of long-term or abandoned sites, baseline data are needed as well. Rainfall, rain pH and rain analyses are needed as well. Perhaps the appropriate leaching medium for any given site is the liquid which filters through a system of local soil subjected to having local rainwater poured over it. In fact, a total geological and hydrological study of the vicinity of the site is likely to be necessary. Again, standard practices, tests and data reporting protocols are required. The California Air Resources Board has suggested a series of estimate air emissions from landspreading, surface impoundments, and landfills containing constituents often found in hazardous wastes. In the absence of consistent methods, conflicting results are likely to occur.

f) Determination of potential for harm:

o Quantitative determinations of constituents present must be carried out in order to determine possibility of exposure of humans or ecosystems to the constituents of the site. This requirement implies development of a measurement assurance program so that the results from complex and expensive tests such as GC/mass spectrography can be translated, on a controlled basis, to less complex and less expensive tests having similar precision and accuracy. Of course, a valid sampling technique is implied as well.

In this context, the question of guarding against or detecting concentrations above a certain datum becomes of interest. The datum may be set by regulatory action or the probability of adverse effects if the concentration exceeds some datum which may have been determined empirically. In any event, classical statistical considerations (nonparametric tolerance limits) can be used to determine how many samples must be investigated in order to calculate some probability of finding a proportion of the total population below the datum. For example, for a probability of 99 percent that 99 percent of all possible tests will be below the largest concentration measured, some 459 separate analyses are required. Conversely, if four separate analyses (replicates) are performed, one can only be 70 percent certain that 70 percent of all possible tests will fall below the largest of the four concentration values measured.

Research is needed to determine the relationship between easily measured parameters, e.g., pH, and the potential for adverse effects. In any case, statistical uncertainties are likely to make "legally accurate" concentration determinations difficult to achieve.

o Kinetics of what is present in terms of local surroundings

In this case, research is required to determine constituents and their concentrations as they move in a specific ecosystem by a variety of paths as a function of time. This problem is the monitoring problem, i.e., concentration as a function of distance and time to define increased exposure to the contents of the site.

If all of the needs described to this point were met, i.e., rapid, accurate qualitative and quantitative measurements of effluents from the site in a statistically valid fashion, the net result would be a determination of exposure to the contents of the site as well as a determination of who and what are exposed at a given level. No mistake should be made in thinking that obtaining these data is simple, straightforward or inexpensive in terms of professional talent, equipment and dollars. Yet, without these data, no valid statement concerning exposure levels can be made.

The W.E.T. scheme utilizes simple dispersion relations and some subjective judgments based on common sense to arrive at a scoring system for exposure via several paths for various potentially harmful substances.

For a real situation, the distribution of the cumulative probability for adverse effect of a sum of various constituent concentrations at a given time and place is required. Clearly, the preference of any model builder will be to obtain a valid continuous function to represent observed discrete measurement values. The choice of logarithmic scaling by the W.E.T. Model allows simple dispersion relations since the errors of these relations coupled with measurement errors will not cause rapid W.E.T. scale changes. Whether or not more accurate theoretically representations are considerably more useful in a practical sense is impossible to state given the data available.

Determining the Exposed Population

The W.E.T. Model builders did not discuss in detail how to isolate the exposed population. In fact, determining the exposed population, i.e., the group subjected to higher than baseline concentrations of the substances from a site, is no simple challenge. In principle, the various paths by which substances might reach the group can be identified. Monitoring, which relies on qualitative and quantitative determinations, at various points away from the site can be implemented. Thus, what--if anything--is escaping and how much will be known as a function of distance from the site. When the slope of the concentration against distance curve changes upward, the boundary for a particular path can be located. Wind, other climatic factors, and water flow patterns may well alter the results over a period of time. Airborne or rain-based factors may enter. Concentrations of substances produced by other means than the waste disposal site may intervene, e.g., from the plants generating the waste or other sources. Thus, attempting unambiguous identification of who is exposed to higher concentrations of potentially harmful substances from a waste disposal site is likely to be exceedingly difficult, time-consuming, expensive, and inaccurate.

But, even if the exposed population, N, could be accurately determined and the risk of excess cancer or other disease were known accurately, prediction of adverse events due to hazardous waste requires a statistical estimation scheme. Since the risks tend to be fairly small in a probabilistic sense, the Poisson distribution function would seem to represent the appropriate statistical estimator.

Consider the Poisson function:

$$P_k(t) = e^{-qt} \frac{(qt)^k}{k!} \qquad (7a)$$

$P_k(t)$ is probability that exactly "k" events occur in half-closed time interval of length equal to "t." q is a parameter indicating average number of illnesses per unit time.

Define:

(7b) $\lambda \equiv qt$, the expected number of illnesses.

Then, the Poisson distribution function is

$$F(x) = \sum_{k=0}^{h} P_k(t) = \sum_{k=0}^{h} \frac{\lambda^h}{k!} e^{-\lambda} \tag{8}$$

F(x) is the probability that the number of illnesses actually observed, S, is less than or equal to "X". $h = [x]$ is the integer satisfying $h \leq x < (h+1)$.

Tables of probabilities according to the Poisson distribution can be found in most statistics textbooks. Basically, determining the excess risk for adverse effect renders the exposed population dichotomous, i.e., a proportion "p" of the individuals have a certain characteristic (illness due to the hazardous waste) while the remaining proportion (1-p) do not have it. For a Poisson distribution $N_p \equiv \lambda$. Thus, if 1000 persons were exposed to 1.1 PPM of chloroform in their water according to figure (2), the risk (or p) is 10^{-3} and $\lambda = N_p = (1000)(10^{-3}) = 1.0$. Figure (9) shows F(x), the probability of the number of illnesses observed versus a discrete number of individuals, X, from the population, N, for several values of λ. For example, with λ = 1.0 we may be 37 percent certain that no one will be harmed and 100 percent certain that no more than five persons will be harmed. (For ingestion of water from a hypothetical well containing the highest detected concentrations of commonly found contaminants, p has been estimated at 7.5×10^{-4} or if N is 1300, then $\lambda = 1.0$.) But if the value of λ increases, say because of contaminants escaping from a hazardous waste facility, the distribution of probability for adverse effect shifts and broadens as shown in figure (9). Therefore, for a population of citizens who have been exposed, a key question is "What is the value of λ for our group?" A second key question is "What is the probability that no one will be harmed as a function of concentration of some substance having a given W.E.T. score, W?"

In order to approach answers to these questions, some assumptions must be made:

- The population exposed is representative of the U.S. population in age and general health characteristics.
- The hazardous waste contaminants are the only external source of adverse effect on this population.

Since λ is defined as N_P and since in turn, P may be defined as mC_x in the linear hazard-concentration range, then by Equation (6):

(9) $\lambda = 10^{(W-10)} NC_x$ where

W is W.E.T. score, H + E

N is population exposed to a substance having a W.E.T. score of W for the path of interest, and

C_x is the concentration in parts per billion (PPB) of the substance in the path of interest. C_x is in PPB.

Figure 10 shows λ as a function of concentration for various values of W. The detection limit for many substances in air or water media is about 5 to 10 PPB; for soils and sediments this limit is about 25 to 100 PPB. As a waste management strategy, if $0 \leq W \leq 5$, the material can be handled in any facility such that escape of constituents resulting in a concentration of up to 100 PPB can be isolated from the general ecosystem near the facility. For $6 \leq W \leq 7$, some judgment will be needed on the ability of the facility to be isolated from the ecosystem. For W of 8 or more, destruction is often likely to be necessary since, if even a small group is exposed to concentrations *below* the detectability limit, the probability for harm may be fairly high. Of course, each situation will need to be considered individually in order to make practical decisions. For example, if proof exists that a proposed or existing landfill operation is essentially isolated from water sources and if the site is also isolated with respect to people, then landfill for substances up to W = 8 or more might be given consideration.

The statistical probability that no one is likely to be harmed by exposure to some concentration of a potentially hazardous substance can be calculated. This probability is given by the first term in the Poisson series:

(10) $P_o = \exp(-\lambda)$

since $F(x) = \frac{\lambda^x}{x!} e^{-2} = e^{-2}$ for $x = o$

Figure 11 shows P_o versus λ for $0.01 \leq \lambda \leq 10$.

From Equation (7b):

(11) $P_o = \exp - [mNC_x]$

From this expression, the absolute value of the error on P_o can be found as:

$$(12)\quad |\Delta P_o| \simeq |P_o \ell n P_o \; [\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta C_x}{C_x}\right)^2]^{1/2}|$$

Figure 12 shows $|P_o|$ for various values of P_o as a function of the composite error in determining the population exposed, the concentration and the value of the slope relating hazard to concentration.

If Equation (9) is utilized, then

$$(13)\quad P_o = \exp - [10^{(W-10)}\ NC_x]$$

Figure 13 shows the probability that no one in an exposed population assumed as 1000 persons will be harmed if detectable concentrations, C_{DL}, of 5, 50, and 80 PPB of some substance having a given W value are confirmed. The curves shown also indicate the changes in P_o if errors in C_{DL} are made; say by actually having 80 PPB present but apparently measuring 50 PPB. In addition, if N were 10,000 rather than 1000, and C_{DL} was 5 PPB, one would be able to read P_o from the C_{DL} = 50 PPB curve. Curves similar to those shown in figure 13 can be used to evaluate specific situations.

Consequences of the W.E.T. Model Scaling System

Since any value of the W.E.T. score W in the range $0 \leq W \leq 5$ produces little change in the statistical risk distribution very little, the most economically advantageous method for treatment and disposal can be chosen by the parties of interest, e.g., generator, service company, regulators--local, State, or Federal. Furthermore, the range of $0 \leq W \leq 5$ allows fairly wide latitude in groups of contaminants, concentration and exposure allowed. For $5 < W \leq 7$, more care is required in choosing appropriate strategies; specific situations will need to be decided on a case basis.

When W exceeds 6, several strategies are possible. For liquid wastes where W exceeds 6, incineration will probably be recommended, since landfilling "free liquids" is likely to be strongly opposed in the political arena. But treatment plants purporting to blend and neutralize various liquid wastes might be allowed to take such wastes. After treatment, the W value might be reduced to 6 or less. Then solidification or encapsulation might be chosen as the "ultimate" disposal method depending on the economic tradeoffs vis-a-vis incineration. For viscous materials, i.e., most sludges, the range $6 < W \leq 8$ will create uncertainties as to proper treatment. As a guess, local authorities will be left to deal with this problem. The same is likely to be true of solids.

For the range where W exceeds 8, destruction is likely to be the choice of most of the parties-of-interest in view of the potential liabilities. However, in some cases other choices may be justified.

In the case of abandoned sites, the W.E.T. model scaling allows a radial distance for cleanup to be chosen quickly, since an acceptable value of the "How clean is clean?" question is answered as soon as P_o is chosen for all potential escape paths and the W values and concentrations of the constituents are found.

The W.E.T. Model Scaling System allows for relatively straightforward monitoring and post-closure costs. First, relatively large changes in concentration of escaping constituents make small changes in the value of the probability for harm (figs. 10 and 13). Thus, time should be available to observe and, if necessary, to take remedial action without alarming the surrounding population.

With regard to insurance issues, the range $0 \leq W \leq 5$ should lead to one band of lower premiums, the range $6 \leq W \leq 8$ should be the next risk band, while for $W > 8$, the highest premium will be required. If liability and regulatory decisions are based upon these three bands, e.g., little liability for $W < 5$ or 6, then the hazardous waste problem can be reduced to economically manageable proportions for the generators.

The key issue will be to convince the public that the W.E.T. Model represents reality with respect to the perceived risks. If this can be done, the nature of the scaling system allows for hazardous waste management at an acceptable economic cost to the generators. Furthermore, one can argue that the scaling system provides for "degree of hazard" at lowest implementation costs--both technical and administrative. Indeed, the scaling system does provide two or three breakpoints for degree of hazard, i.e., $W < 5$, $5 < W \leq 7$ or 8, and $W \geq 8$.

Some Broad Economic Implications of Adoption of the W.E.T. Model

Generators: Cost could be reduced for managing hazardous wastes since much solid material can go to landfill, i.e., $W \leq 5$. For very low W values, delisting might be in order. Obviously, liability and insurance costs are likely to be reduced as well if it can be shown that the generator's wastes prior to treatment and disposal had a low value for W.

Service Companies: Rules are clear--keep W as low as possible. If the value of W can be proven, then the company is in "compliance with regulations." Hence, liability, insurance, analytical and monitoring costs can be reduced. Profitability should increase at slightly lower gross charges per ton as some of these savings are bartered back to customers of the facility. Prices for disposal will probably increase as W increases.

Transporters: A uniform manifest system showing the "W" value of the waste as it leaves the generator should reduce transporter liability and might lower transport costs and opposition to transport through certain jurisdictions. In any case, a fixed system will be in place in order to serve as a foundation for whatever precedents the courts set.

Regulators: The W.E.T. Model allows for considerable bargaining in setting regulations, since, within reason, regions of W can be selected to give regulations a "tough" or "easy" appearance without substantially altering real risk.

Sitting Commissions: A framework to ease public fear of morbid consequences would exist. Then negotiations for a facility could proceed on more conventional lines, i.e., economic bargaining. The same apparent latitude available to regulators would exist.

Incinerator Operators (Land and Sea): Most wastes and all liquids with W > 6 are candidates for destruction.

The General Public: If costs of disposal do decrease, perhaps some of these savings will wend their way indirectly to the general public. The key for advocates of the W.E.T. scheme is to get the public to think in W.E.T. Model scaling numbers rather than actual risks.

General Conclusion

The W.E.T. Model can provide a framework for hazardous waste management which is likely to be acceptable to most parties-of-interest. The key is to understand all of the technical, legal, and economic implications of the Model so as to be able to negotiate the strongest position for one's own interests.

Certainly, the Model can be manipulated to reach almost any desired outcome provided all of its ramifications are clearly understood and can be put in perspective. The key will be to utilize this knowledge for appropriate policy and economic purposes. Since the framework will accommodate most outcomes, manipulation of the Model will allow for flexible control of hazardous waste issues without requiring major policy departures.

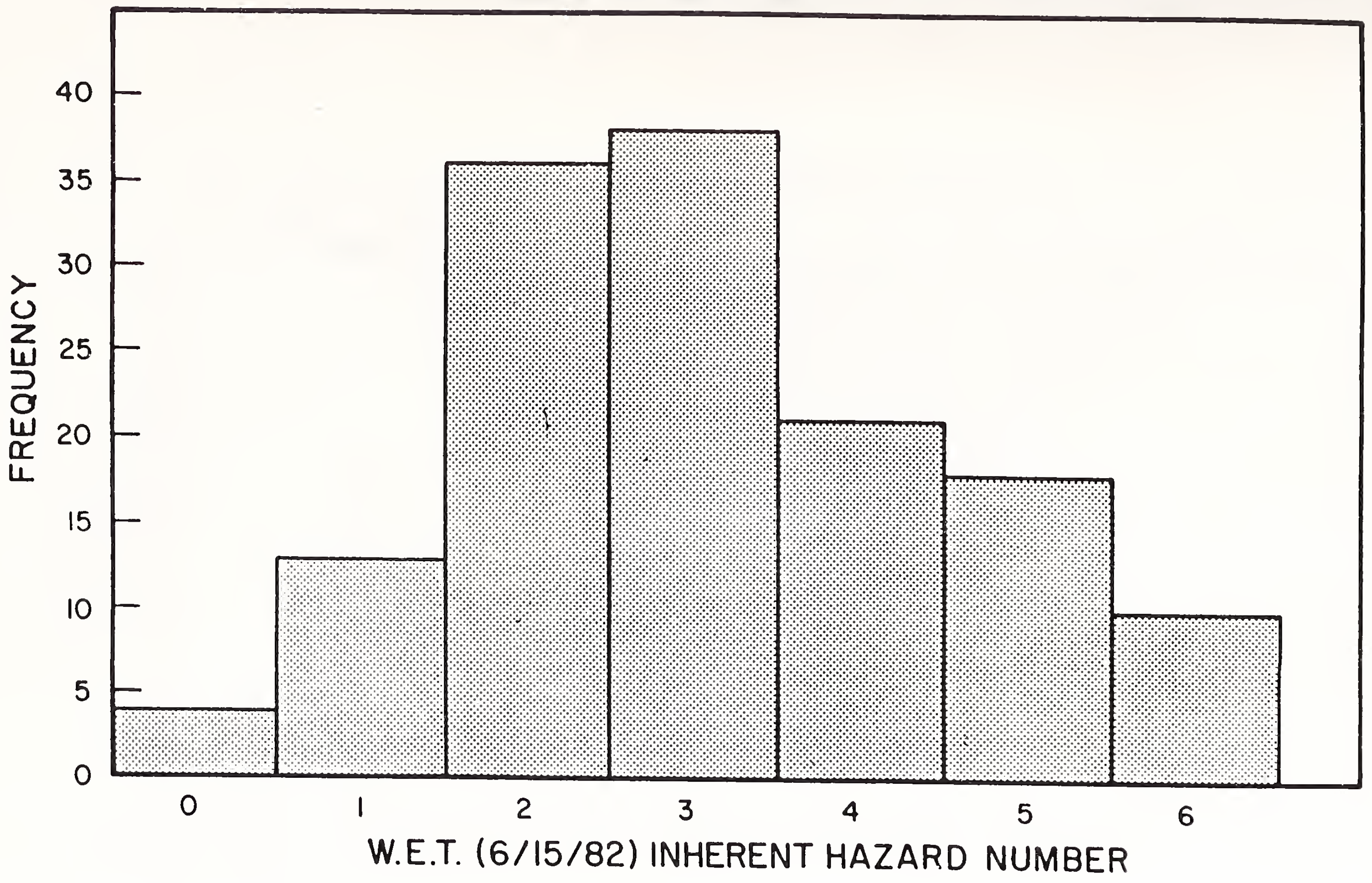


Figure VII.1. Histogram showing inherent hazard, H, scores developed by W.E.T. model builders for 140 hazardous substances (see Appendix I).

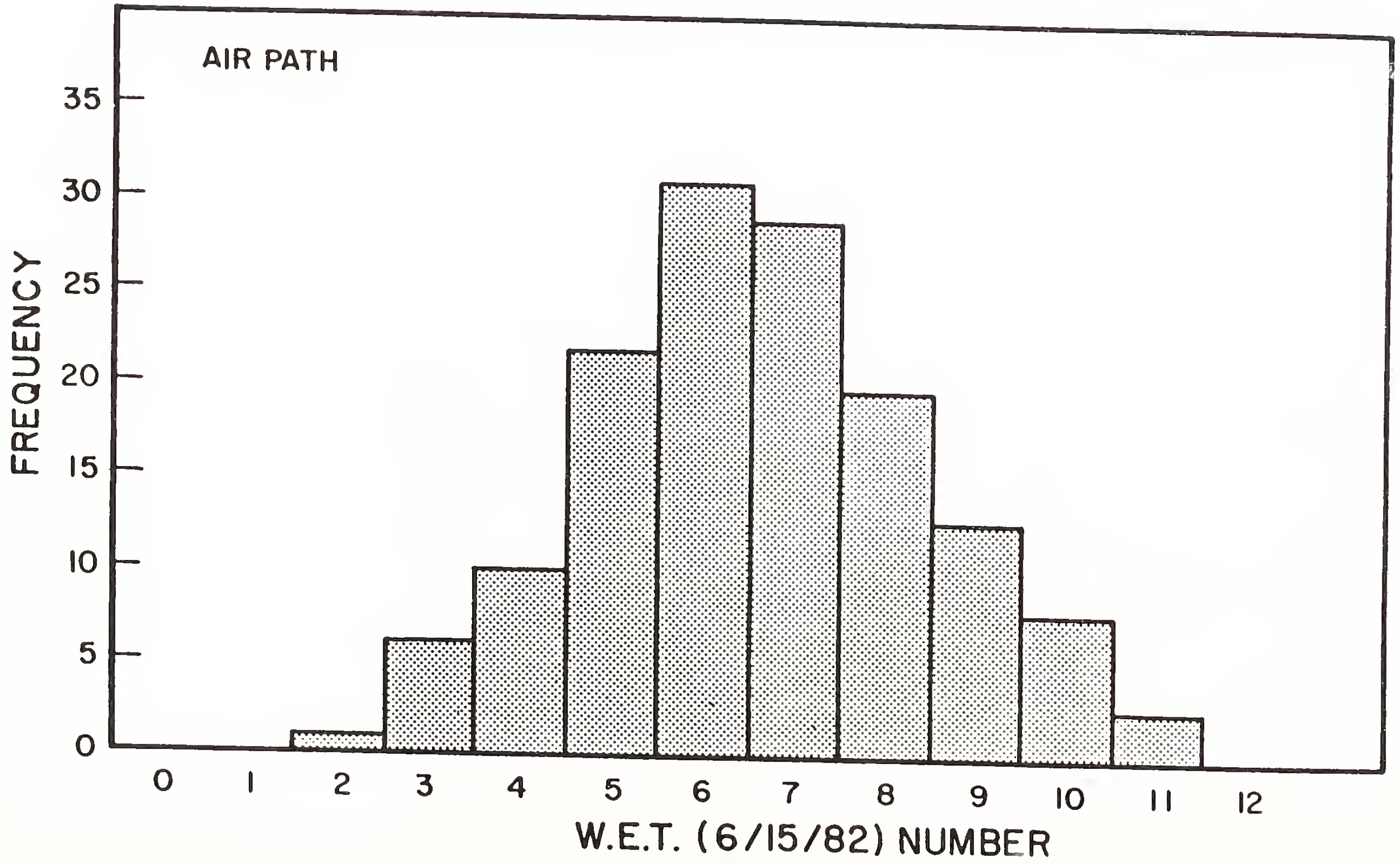


Figure VII.2. Histogram showing W.E.T. model scores, $W \equiv H + E_{AIR}$ for 140 hazardous substances via air path.

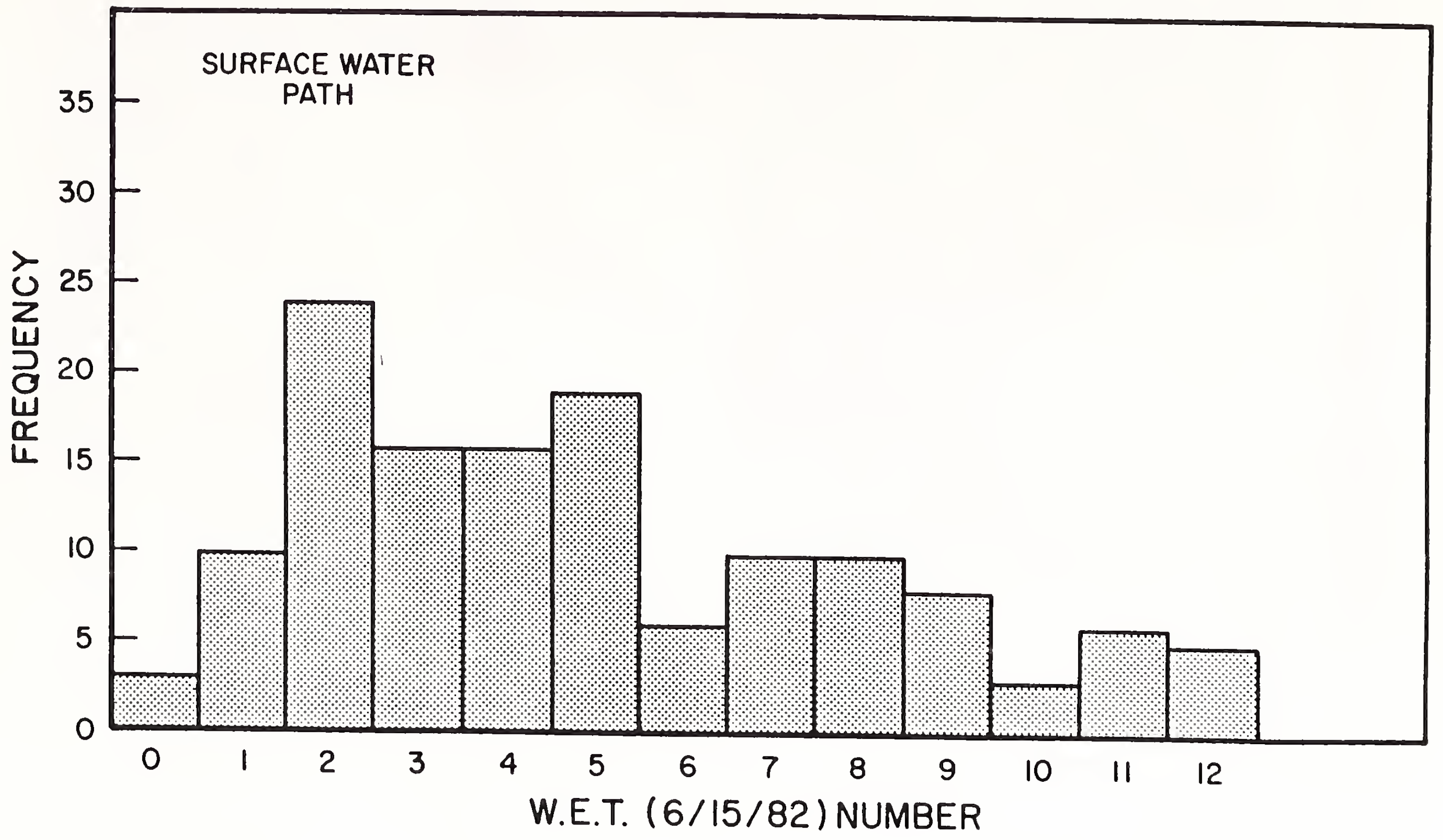


Figure VII.3. Histogram showing W.E.T. model scores, $W \equiv H + E_{SW}$, for 140 hazardous substances via surface water path.

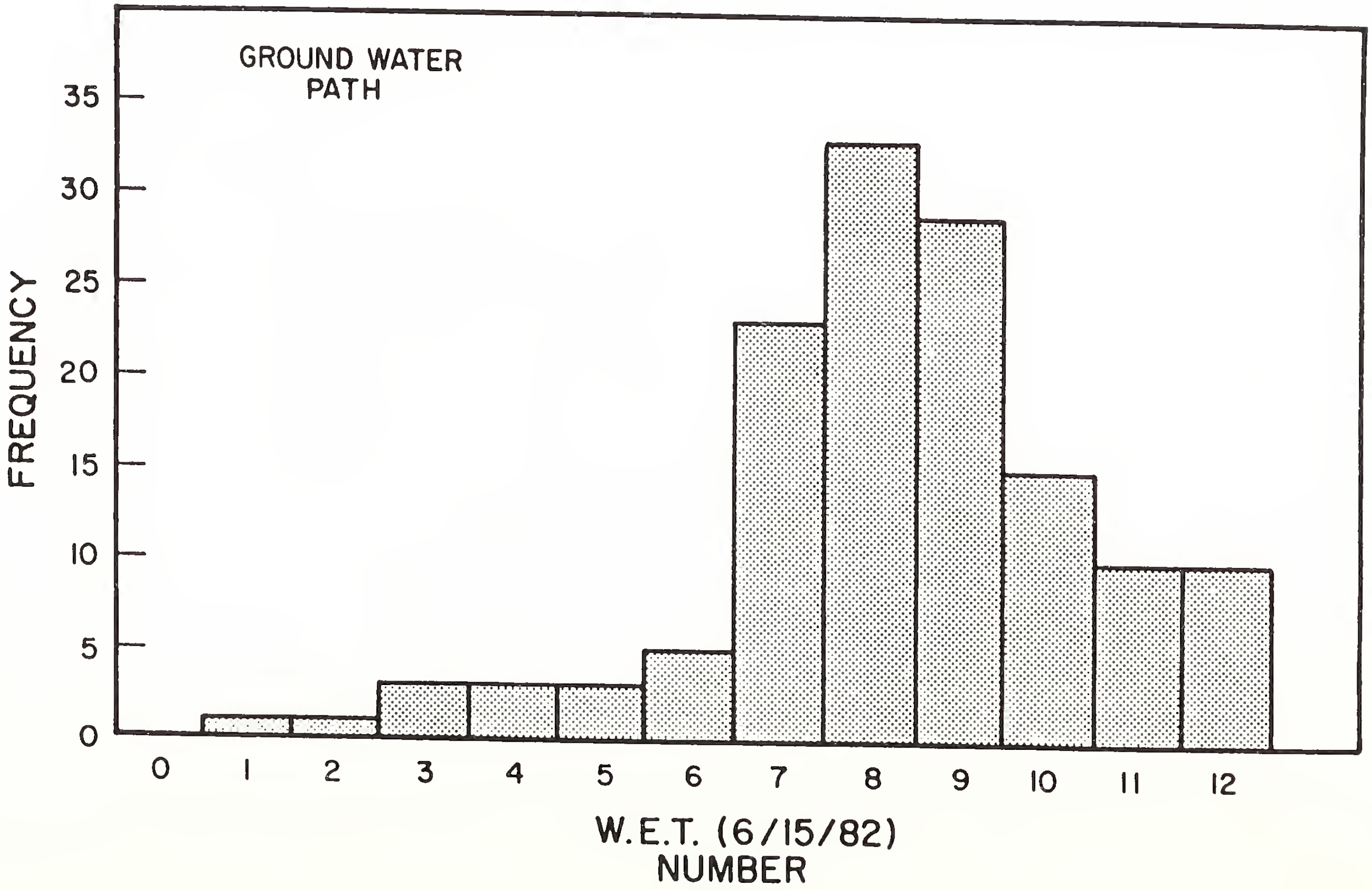
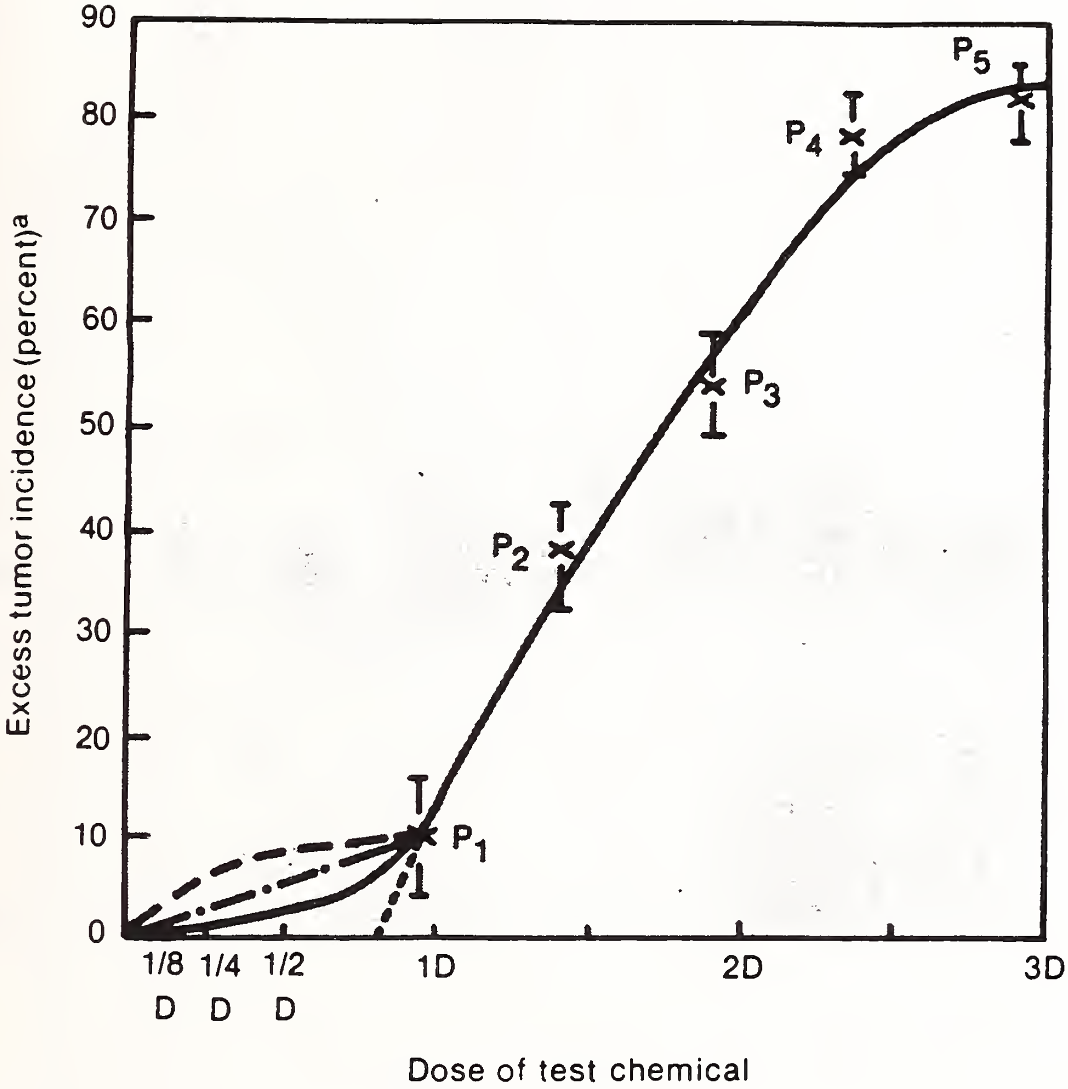


Figure VII.4. Histogram showing W.E.T. model scores, $W \equiv H + E_{GW}$, for 140 hazardous substances via ground water path.



[a] Excess tumor incidence (percent) is defined as:

$$\left(\frac{\text{tumors in exposed population}}{\text{number of exposed population}} - \frac{\text{tumors in control population}}{\text{number of exposed population}}\right) \times 100$$

—— a sigmoid dose-response curve; infralinear between O and P₁

—·—·— linear extrapolation

— — — supralinear extrapolation

------ line projected to a threshold

SOURCE: Office of Technology Assessment.

Figure VII.5. A stylized dose-response curve and some extrapolated curves.

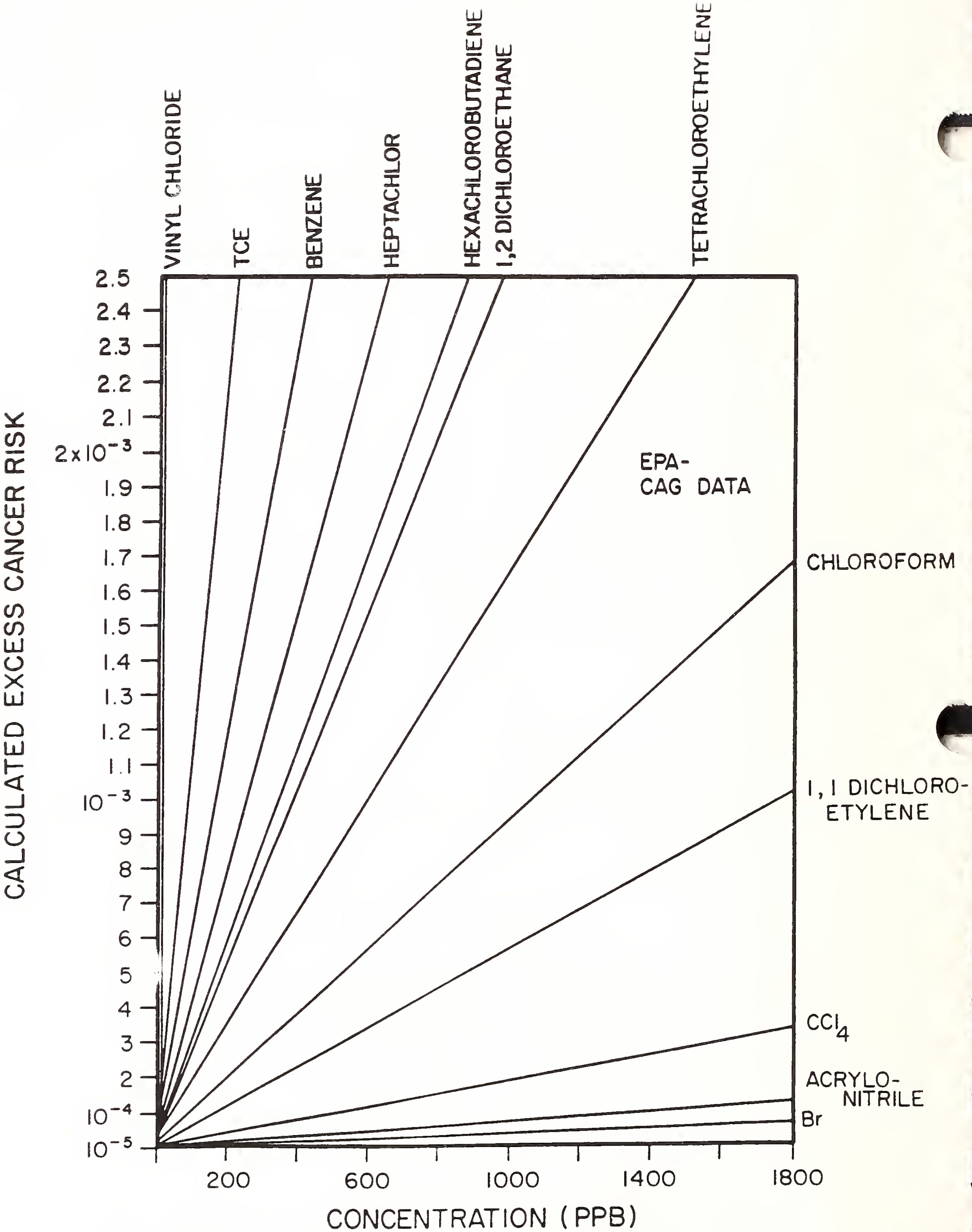


Figure VII.6. Calculated excess cancer risk as a function of concentration of chemicals shown in drinking water. Assumes linear dose-response relationship in region shown. (EPA Carcinogen Assessment Group Data.)

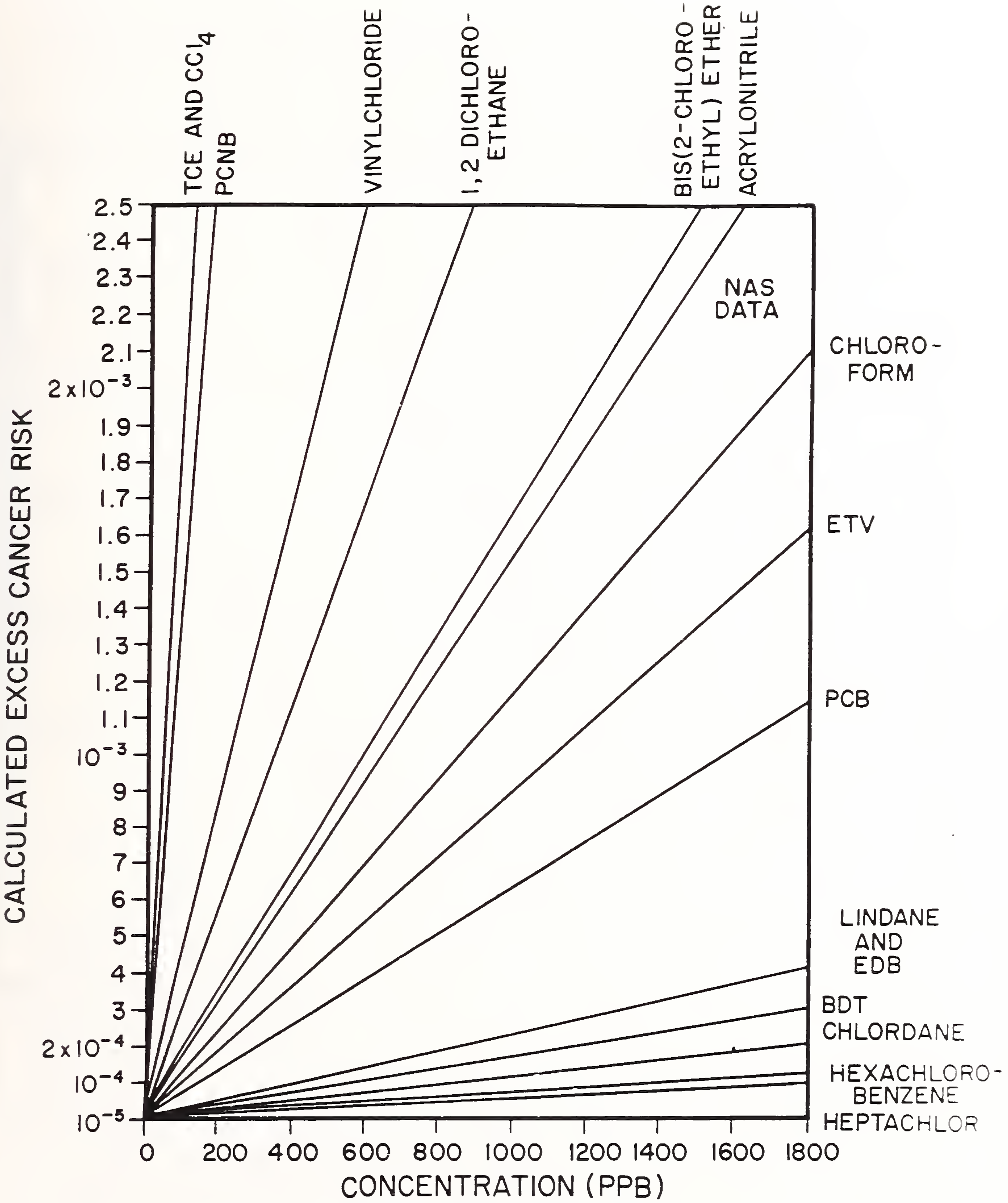


Figure VII.7. Calculated excess cancer risk as a function of concentration of chemicals shown in drinking water. Assumes linear dose-response relationship in region shown (National Academy of Sciences data).

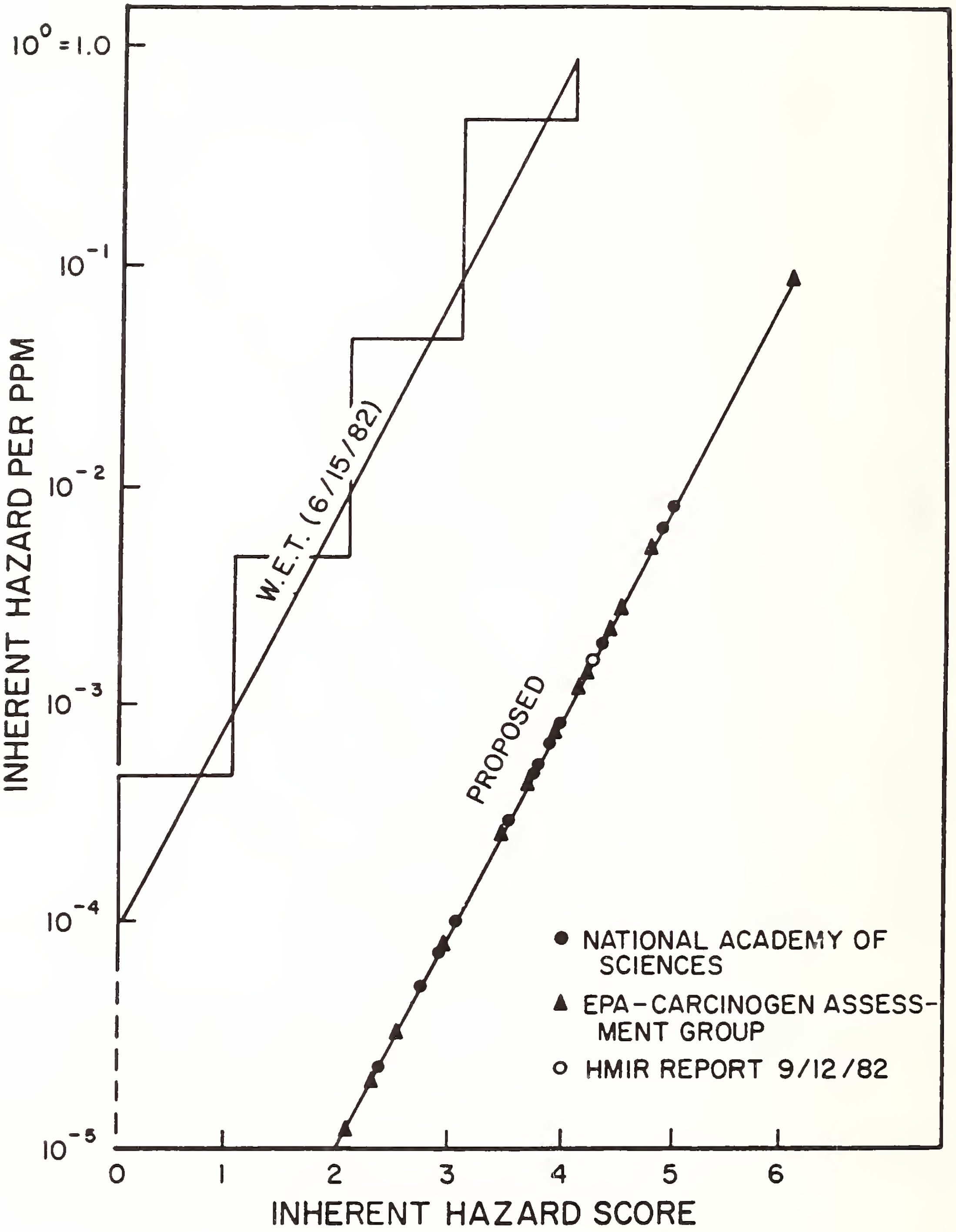


Figure VII.8. Inherent hazard score as a function of inherent hazard as given by the W.E.T. model builders (Table 1) and as proposed in terms of the data in Table 2.

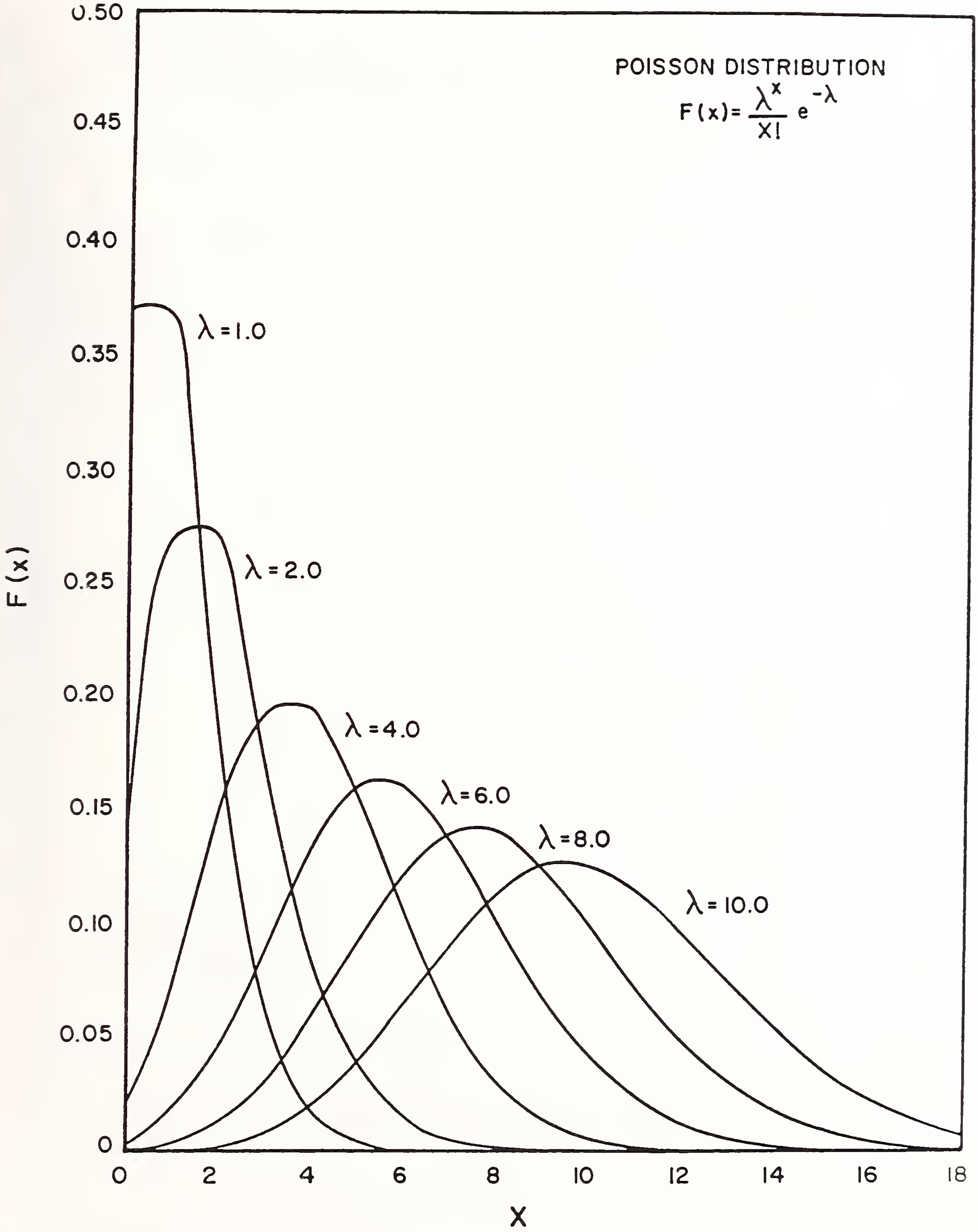


Figure VII.9. Poisson distribution probability, F(x), versus number affected, x. Distributions are shown for several values of λ_i in addition the corresponding values of $W \equiv ET_x$ for a population of 1000 are also shown.

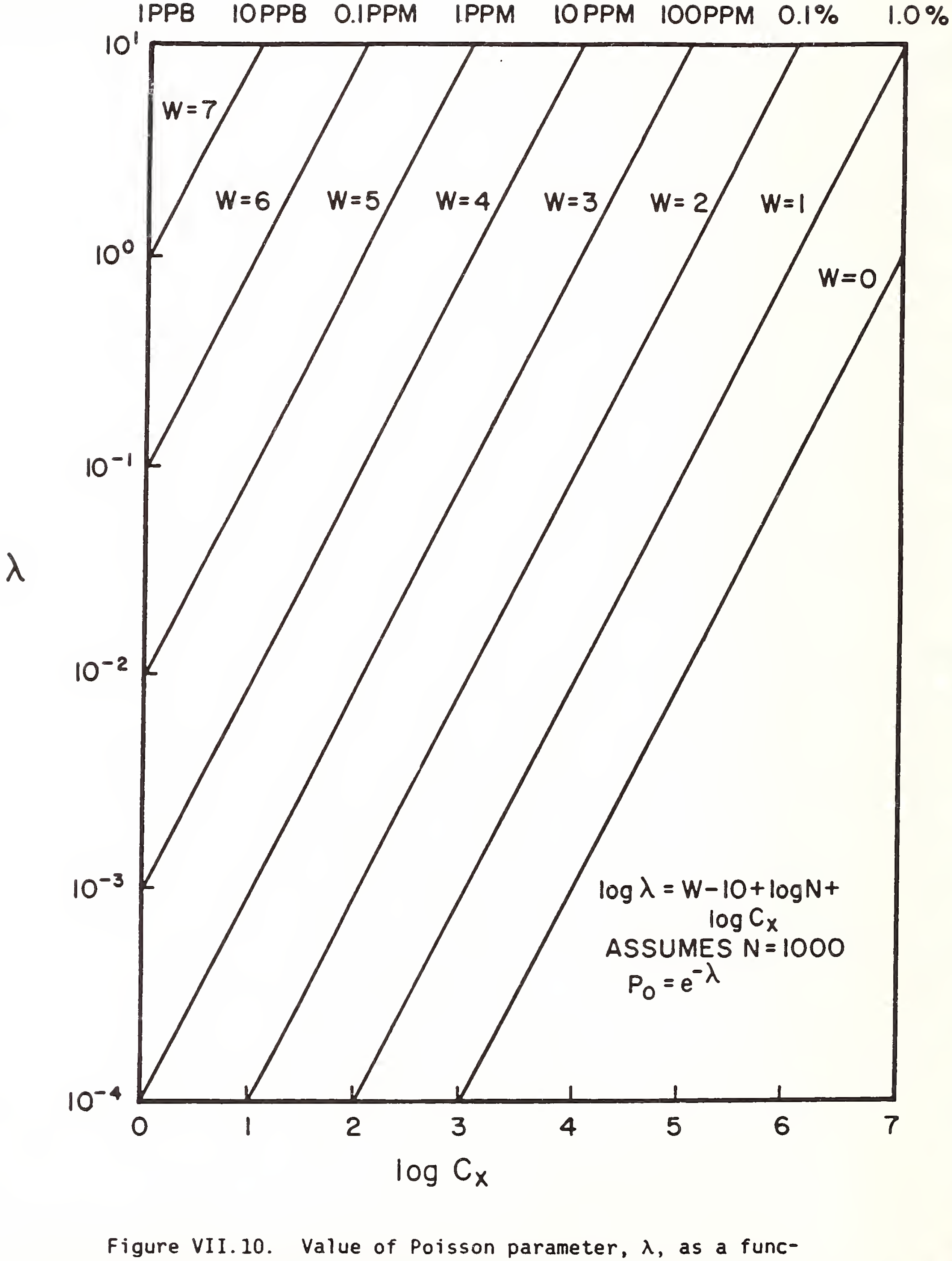


Figure VII.10. Value of Poisson parameter, λ, as a function of concentration of potentially hazardous substance for various W.E.T. scores, W.

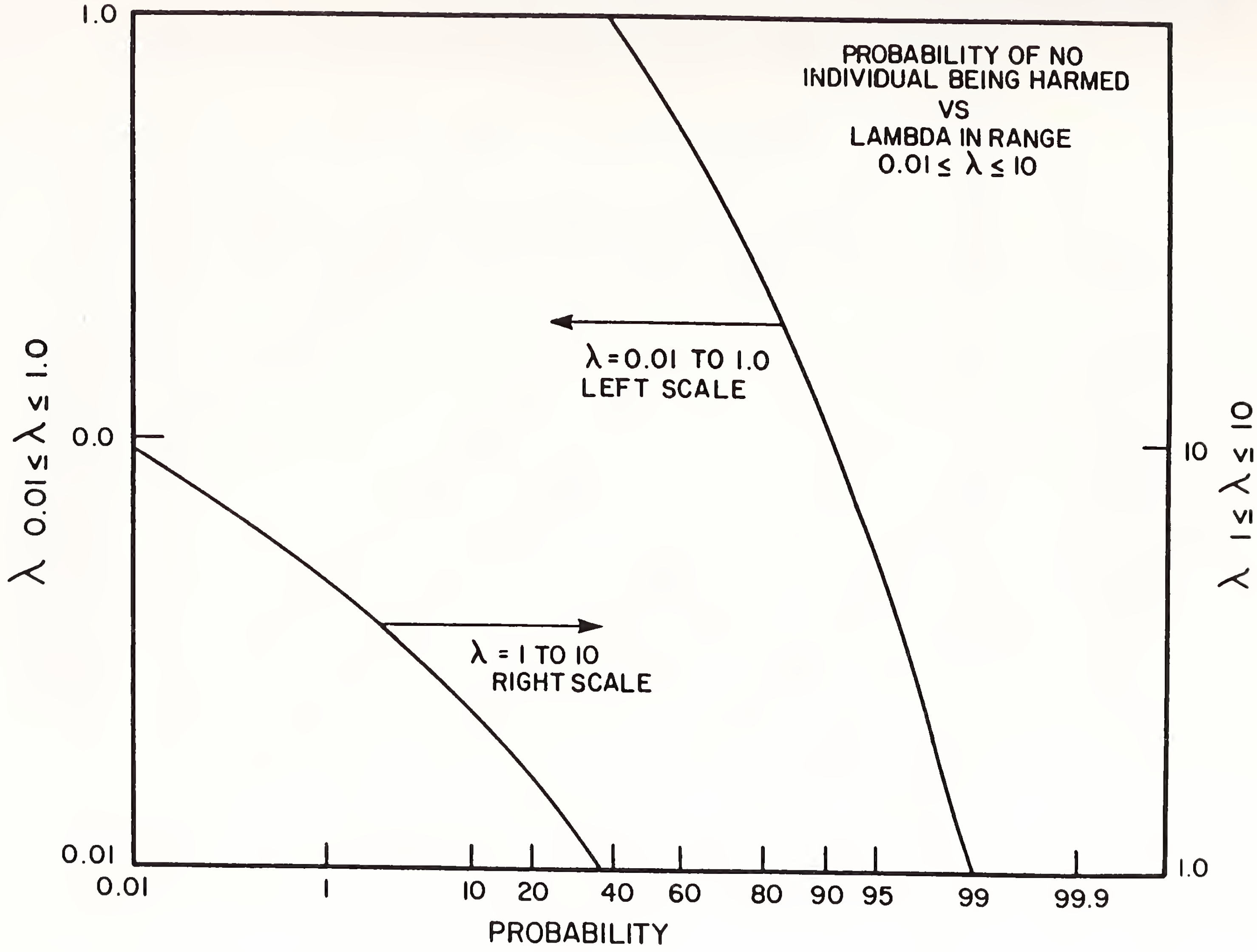


Figure VII.11. Probability that no individual will be harmed, P_o, as a function of Poisson parameter, λ.

$$mNC_x = -\ln P_o$$

$$P_o \ln P_o \left[\frac{\Delta C_x}{C_x} + \frac{\Delta N}{N} + \frac{\Delta m}{m} \right] = \Delta P_o$$

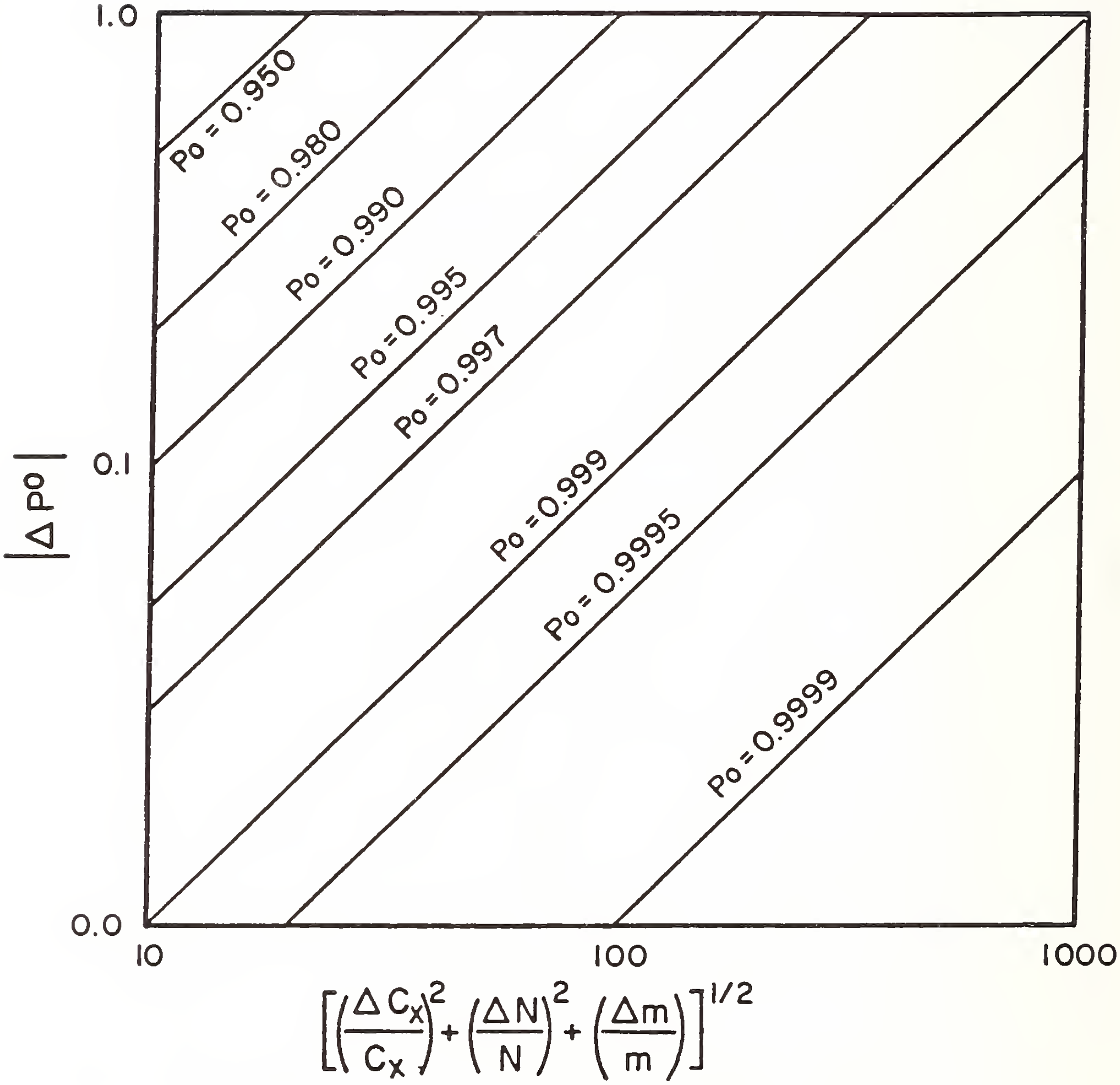


Figure VII.12. Absolute values of the expected uncertainty in the probability that no one will be harmed by exposure to a potentially hazardous substance as a function of uncertainties in determining the concentration of the substance, "C_x," the total population exposed, "N", and the relationship between hazard and concentration, "m".

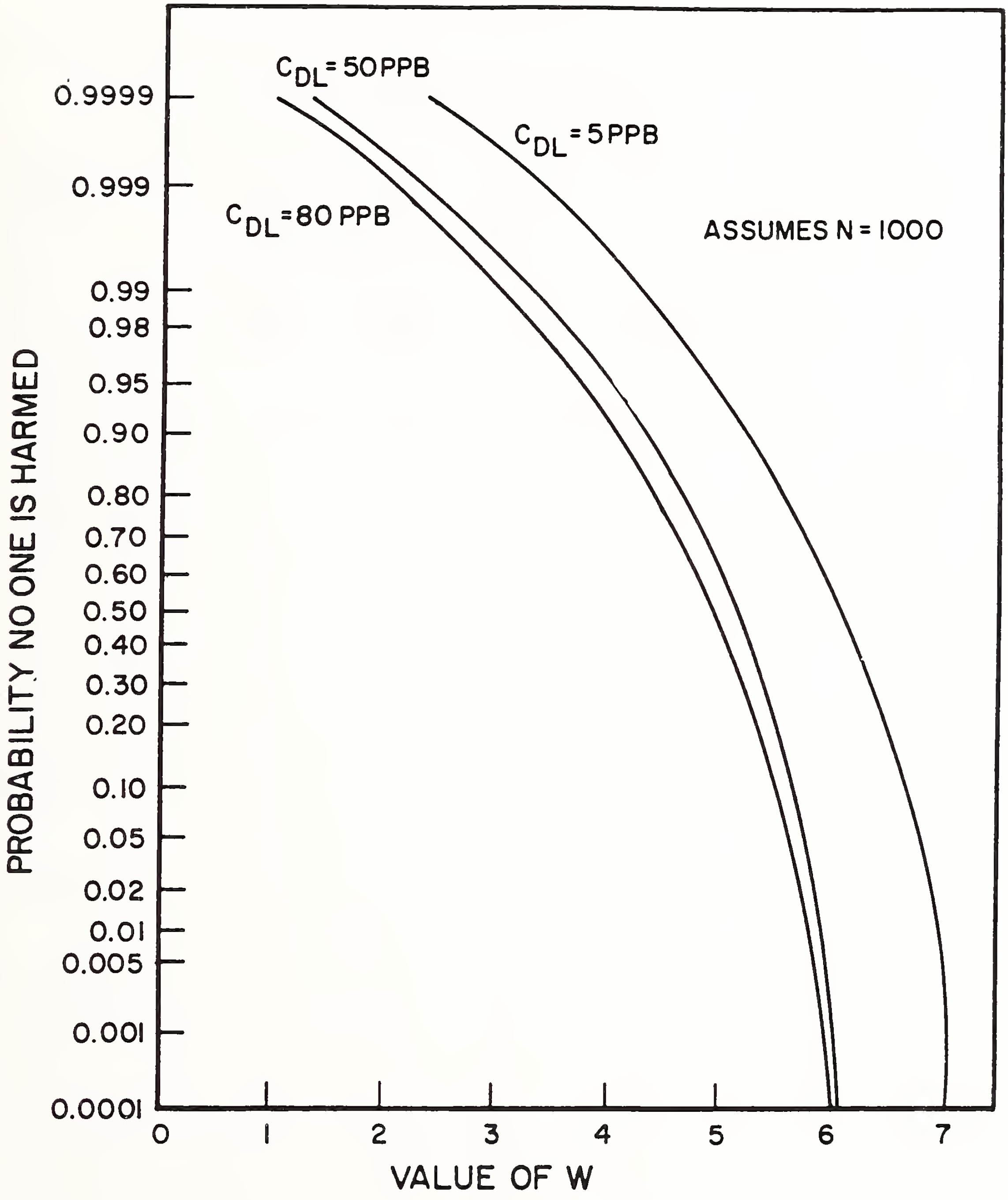


Figure VII.13. Probability for no one in an exposed population of 1000 persons being harmed for detectability limit concentrations shown as a function of W.E.T. score, W.

SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments: Air B	Exposure Adjustments: Surface Water C	Exposure Adjustments: Ground-water D	Adjusted Inherent Hazard by Medium: Air E (A+B)	Adjusted Inherent Hazard by Medium: Surface Water F (A+C)	Adjusted Inherent Hazard by Medium: Ground water G (A+D)
Acenaphthene	3	3	2	6	6	5	9
Acenaphthylene	3	3	2	5	6	5	8
*Acetaldehyde	2	2	0	7	4	2	9
*Acetonitrile	2	6	0	7	8	2	9
Acrolein	5	2	0	7	7	5	12
Acrylamide	3	2	4	6	5	7	9
*Acrylonitrile	5	3	0	7	8	5	12
4-Aminobiphenyl	4	2	0	0	6	4	4
Anthracene	3	4	4	5	7	7	8
*Antimony	5	4	7	7	9	12	12
*Arsenic	5	4	7	7	9	12	12
Asbestos	3	4	4	0	7	7	3
α-BHC	2	5	3	5	7	5	7
β-BHC	2	5	3	5	7	5	7
γ-BHC	2	5	3	5	7	5	7
*Barium	3	4	4	4	7	7	7
*Benzene	2	4	0	6	6	2	8
Benzidine	2	3	0	0	5	2	2

SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments: Air B	Exposure Adjustments: Surface Water C	Exposure Adjustments: Ground-water D	Adjusted Inherent Hazard by Medium: Air E (A+B)	Adjusted Inherent Hazard by Medium: Surface Water F (A+C)	Adjusted Inherent Hazard by Medium: Ground-water G (A+D)
*Benzo(a)anthracene	2	4	6	5	6	8	7
*Benzo(a)pyrene	6	4	6	5	10	12	11
Benzo(g,h,i)perylene	3	4	8	5	7	11	8
Benzo(k)fluoranthene	3	4	6	5	7	9	8
3,4-Benzofluoranthene	2	4	6	5	6	8	7
Beryllium	6	4	2	2	10	8	8
Bis(2-chloroethoxy)-methane	3	1	0	0	4	3	3
*Bis(chloromethyl)ether	5	1	0	0	6	5	5
Bis(2-ethylhexyl)-phthalate	1	3	6	6	4	7	7
Butane	0	3	0	7	3	0	7
Butene/Butadiene	0	2	0	7	2	0	7
*Cadmium	5	4	6	5	9	11	11
Carbon disulfide	5	6	0	7	11	5	12
*Carbon tetrachloride	3	8	0	6	11	3	9
*Chlordane	3	4	0	5	7	3	8
*Chloroacetaldehyde	4	3	0	6	7	4	10
4-Chloroaniline	2	3	1	5	5	3	7
*Chlorobenzene	3	4	0	6	7	3	9

SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground-water D	Air E (A+B)	Surface Water F (A+C)	Groun water G (A+D
*Chloroform	3	5	0	6	8	3	9
4-Chloro-2-methylphenol	2	3	0	6	5	2	8
2-Chlorophenol	2	3	0	7	5	2	9
*Chromium (VI)	5	4	7	7	9	12	12
*Chrysene	4	4	6	5	8	10	9
*Copper	3	4	1	1	7	4	4
Creosote	2	2	1	7	4	3	9
*Cyanide	4	7	0	7	11	4	11
Cyclohexane	2	3	0	6	5	2	8
Dibenzo(a,h)anthracene	4	4	5	5	7	9	9
Di-n-butyl phthalate	2	3	3	6	5	5	8
*1,2-Dichlorobenzene	1	4	1	6	5	2	7
1,3-Dichlorobenzene	1	4	1	6	5	2	7
*1,4-Dichlorobenzene	2	4	1	6	6	3	8
3,3-Dichlorobenzidine	2	3	0	5	5	2	7
*1,2-Dichloroethane	3	4	0	6	7	3	9
*1,1-Dichloroethene	3	4	0	6	7	3	9
*Dichloromethane	2	4	0	7	6	2	9
2,4-Dichlorophenol	2	3	1	6	5	3	8

SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments: Air B	Exposure Adjustments: Surface Water C	Exposure Adjustments: Ground-water D	Adjusted Inherent Hazard by Medium: Air E (A+B)	Adjusted Inherent Hazard by Medium: Surface Water F (A+C)	Adjusted Inherent Hazard by Medium: Ground-water G (A+D)
2,4-Dichlorophenoxy-acetic acid	2	3	0	5	5	2	7
1,2-Dichloropropane	2	4	0	6	6	2	8
1,3-Dichloropropene	4	2	0	6	6	4	10
O,O-Diethyl S-(2-(ethylthio)ethyl) ester of phosphorothioic acid	4	4	3	5	8	7	9
O,O-Diethyl phosphoric acid O-p-nitrophenyl ester	4	4	3	5	8	7	9
1,2-Dimethyl hydrazine	4	2	0	6	6	4	10
2,4-Dimethyl phenol	4	2	2	6	6	6	10
Dimethyl phthalate	0	4	1	6	4	1	6
Dimethyl sulfate	4	0	0	0	4	4	4
4,6-Dinitro-2-methylphenol	3	3	1	6	6	4	9
2,4-Dinitrophenol	3	3	1	6	6	4	9
*2,4-Dinitrotoluene	3	3	1	6	6	4	9
2,6-Dinitrotoluene	3	3	1	6	6	4	9
1,4-Dioxane	2	3	0	7	5	2	9
Dodecane	2	3	0	6	5	2	8
Endrin	4	4	4	5	8	8	9

SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments			Adjusted Inherent Hazard by Medium		
		Air B	Surface Water C	Ground-water D	Air E (A+B)	Surface Water F (A+C)	Ground-water G (A+D)
*Epichlorohydrin	3	4	0	7	8	3	10
Ethylbenzene	2	3	0	6	5	2	8
Fluorene	3	4	2	6	7	5	9
Fluorine *(fluorides)	3	4	7	7	7	10	10
*Formaldehyde	5	3	0	7	8	5	12
*Hexachlorobenzene	3	5	6	5	8	9	8
Hexachlorobutadiene	2	3	0	5	5	2	7
Hexachlorocyclopentadiene	5	3	0	5	8	5	10
*Hexachloroethane	1	7	0	5	8	1	6
Hexachlorophene	3	4	2	5	7	5	8
Hexane	1	3	0	7	4	1	8
Hydrazine	4	2	3	6	6	7	10
Hydrogen chloride	3	4	N/A	N/A	7	N/A	N/A
Hydrogen sulfide	4	4	N/A	N/A	8	N/A	N/A
Indeno(1,2,3-c,d)-pyrene	3	4	6	5	7	9	8
Isophorone	2	4	0	6	6	2	8
*Lead	5	4	3	2	9	8	7
Maleic anhydride	3	2	0	0	5	3	3

SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground-water D	Air E (A+B)	Surface Water F (A+C)	Ground-water G (A+D)
*Mercury	5	4	3	0	9	8	5✓
Methomyl	3	2	2	5	5	5	8
Methyl bromide	3	5	0	6	8	3	9
Methyl chloride	1	5	0	7	6	1	8
*Methyl ethyl ketone	0	3	0	7	3	0	7
Methyl hydrazine	6	2	0	6	8	6	12
Methyl parathion	5	4	3	5	9	3	10
Naphthalene	1	4	0	6	5	1	7
2-Naphthylamine	2	3	3	6	5	5	8
*Nickel	4	4	2	2	8	6	6
*Nitrobenzene	2	4	0	5	6	2	7
Nitrogen oxides	3	3	N/A	N/A	6	N/A	N/A
2-Nitrophenol	2	3	0	6	5	2	8
4-Nitrophenol	3	3	1	6	6	4	9
N-Nitrosodimethylamine	4	3	0	5	7	4	9
N-Nitrosodiphenylamine	1	3	0	5	4	1	6
Octachlorostyrene	3	5	6	5	8	9	8
PCB-1016	5	4	6	5	9	11	10
PCB-1221	5	4	3	5	9	8	10

SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground-water D	Air E (A+B)	Surface Water F (A+C)	Ground-water G (A+D)
PCB-1232	6	4	0	5	10	6	11
PCB-1242	6	4	2	5	10	8	11
PCB-1248	5	4	3	5	9	8	10
*PCB-1254	6	4	4	5	10	10	11
PCB-1260	6	4	5	5	10	11	11
*Parathion	6	4	3	5	10	9	11
Pentachlorophenol	4	3	3	6	7	7	10
Phenanthrene	3	4	2	5	7	5	8
*Phenol	4	2	1	6	6	5	10
Pyrene	3	4	3	5	7	6	8
*Pyridine	2	4	1	5	6	3	7
Selenium	4	4	7	7	8	11	11
Silver	2	4	5	5	6	7	7
Sodium	2	4	7	5	6	9	7
Sulfur dioxide	3	4	N/A	N/A	7	N/A	N/A
2,3,7,8-Tetrachloro-dibenzo-p-dioxin	6	2	5	5	8	11	11
*1,1,2,2-Tetrachloro-ethane	4	6	0	6	10	4	10
*Tetrachloroethene	2	6	0	6	8	2	8

SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground-water D	Air E (A+B)	Surface Water F (A+C)	Ground-water G (A+D)
*Thallium	5	4	0	0	9	5	5 ✓
*Toluene	1	3	0	7	4	1	8
*Toluene diamine	3	3	5	6	6	8	9
*Toluene-2,4-diisocyanate	6	3	3	6	9	9	12
o-Toluidine hydrochloride	1	2	0	0	3	1	1
*Toxaphene	3	4	1	5	7	4	8
1,2,4-Trichlorobenzene	2	4	0	6	6	2	8
*1,1,1-Trichloroethane	1	6	0	7	7	1	8
*1,1,2-Trichloroethane	1	5	0	6	6	1	7
*Trichloroethene	4	3	0	5	7	4	9
2,4,6-Trichlorophenol	1	3	1	7	4	2	8
*Vanadium	5	4	7	7	9	12	12
Vinyl chloride	2	3	0	7	5	2	9
*Zinc	2	4	4	4	6	6	6

*Actually used in one of the data base's 83 waste streams

N/A—not applicable

EXPOSURE ADJUSTMENT SCORES

Half-Life	Air	Surface Water[ab]	Ground Water[bc]
3 minutes	0	-	-
30 minutes	1	0	-
6 hours	2	1	0
3 days	3	2	1
30 days	4	3	2
1 year	5	4	3
10 years	6	5	4
100 years	-	6	5
1,000 years	-	-	6

[a] If bioaccumulation factor in fish is 10^k, add K-2 points for K≥3; leave score unchanged for K≤2.

[b] If chemical is removed by conventional water treatment, subtract factor based on degree of removal (90 percent removal = -1; 99 percent removal = -2).

[c] If adsorbed to solid surfaces, subtract points according to degree of adsorption (99 percent adsorption = -2; 99.9 percent adsorption = -3).

Note: Air scores include removal by atmospheric washout as well as degradation. Surface-water scores include sedimentation and volatilization as well as degradation. Ground-water scores include irreversible adscrption.

UNCERTAINTY SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Groundwater D	Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Groundwater G $\sqrt{A^2+D^2}$
Acenaphthene	1.5	1	1	1	1.8	1.8	1.8
Acenaphthylene	1.5	1	1	1	1.8	1.8	1.8
Acetaldehyde	1	1	1	1	1.4	1.4	1.4
Acetonitrile	1	1	1	1	1.4	1.4	1.4
crolein	1	1	1	1	1.4	1.4	1.4
Acrylamide	1	1	1	1	1.4	1.4	1.4
Acrylonitrile	1	1	1	1	1.4	1.4	1.4
4-Aminobiphenyl	1	1	1	1	1.4	1.4	1.4
Anthracene	1.5	1	1	1	1.8	1.8	1.8
Antimony	1.5	1	1	1	1.8	1.8	1.8
Arsenic	1.5	1	1	1	1.8	1.8	1.8
Asbestos	1	1	1	1	1.4	1.4	1.4
α-BHC	1	1	1	1	1.4	1.4	1.4
β-BHC	1	1	1	1	1.4	1.4	1.4
γ-BHC	1	1	1	1	1.4	1.4	1.4
Barium	1	1	1	1	1.4	1.4	1.4
Benzene	1	1	1	1	1.4	1.4	1.4
enzidine	1	1	1	1	1.4	1.4	1.4

UNCERTAINTY SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground-water D	Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground-water G $\sqrt{A^2+D^2}$
Benzo(a)anthracene	1	1	1	1	1.4	1.4	1.4
Benzo(k)fluoranthene	1.5	1	1	1	1.8	1.8	1.8
3,4-Benzofluoranthene	1	1	1	1	1.4	1.4	1.4
Benzo(g,h,i)perylene	1.5	1	1	1	1.8	1.8	1.8
Benzo(a)pyrene	1	1	1	1	1.4	1.4	1.4
Beryllium	2	1	1	1	2.2	2.2	2.2
Bis(2-chloroethoxy)-methane	1	1	1	1	1.4	1.4	1
Bis(chloromethyl)ether	1	1	1	1	1.4	1.4	1.4
Bis(2-ethylhexyl)-phthalate	1	1	1	1	1.4	1.4	1.4
Butane	1	1	1	1	1.4	1.4	1.4
Butene/Butadiene	1	1	1	1	1.4	1.4	1.4
Cadmium	1	1	1.5	1.5	1.4	1.8	1.8
Carbon disulfide	1	1.5	1	1	1.8	1.4	1.4
Carbon tetrachloride	1	1	1	1	1.4	1.4	1.4
Chlordane	1	1.5	1	1	1.8	1.4	1.4
Chloroacetaldehyde	1	1	1	1	1.4	1.4	1.4
4-Chloroaniline	1	1	1	1	1.4	1.4	1.4
Chlorobenzene	1	1	1	1	1.4	1.4	1.4

UNCERTAINTY SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground Water D	Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground Water G $\sqrt{A^2+D^2}$
Chloroform	1	1	1	1	1.4	1.4	1.4
4-Chloro-2-methylphenol	1	1	1	1	1.4	1.4	1.4
2-Chlorophenol	1	1	1	1	1.4	1.4	1.4
Chromium (VI)	1	1	2	2	1.4	2.2	2.2
Chrysene	1	1	1	1	1.4	1.4	1.4
Copper	1.5	1	1	1	1.8	1.8	1.8
Creosote	1	1	1	1	1.4	1.4	1.4
Cyanide	1.5	1	1	1	1.8	1.8	1.8
Cyclohexane	1	1	1	1	1.4	1.4	1.4
Dibenzo(a,h)anthracene	1	1	1	1	1.4	1.4	1.4
Di-n-butyl phthalate	1	1	1	1	1.4	1.4	1.4
1,2-Dichlorobenzene	1	1	1	1	1.4	1.4	1.4
1,3-Dichlorobenzene	1	1	1	1	1.4	1.4	1.4
1,4-Dichlorobenzene	1	1	1	1	1.4	1.4	1.4
3,3'-Dichlorobenzidine	1	1	1	1	1.4	1.4	1.4
1,2-Dichloroethane	1	1	1	1	1.4	1.4	1.4
1,1-Dichloroethene	1	1	1	1	1.4	1.4	1.4
Dichloromethane	1	1	1	1	1.4	1.4	1.4
2,4-Dichlorophenol	1	1	1	1	1.4	1.4	1.4

UNCERTAINTY SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments: Air B	Exposure Adjustments: Surface Water C	Exposure Adjustments: Ground Water D	Adjusted Inherent Hazard by Medium: Air E $\sqrt{A^2+B^2}$	Adjusted Inherent Hazard by Medium: Surface Water F $\sqrt{A^2+C^2}$	Adjusted Inherent Hazard by Medium: Ground Water G $\sqrt{A^2+D^2}$
2,4-Dichlorophenoxy-acetic acid	1	1	1	1	1.4	1.4	1.4
1,2-Dichloropropane	1	1	1	1	1.4	1.4	1.4
1,3-Dichloropropene	1	1	1	1	1.4	1.4	1.4
O,O-Diethyl S-(2-(ethylthio)ethyl) ester of phosphorothioic acid	1	1.5	1	1	1.8	1.4	1.4
O,O-Diethyl phosphoric acid O-p-nitrophenyl ester	1	1.5	1	1	1.8	1.4	1
1,2-Dimethyl hydrazine	1	1	1	1	1.4	1.4	1.4
2,4-Dimethyl phenol	1	1	1	1	1.4	1.4	1.4
Dimethyl phthalate	1	1	1	1	1.4	1.4	1.4
Dimethyl sulfate	1	1	1	1	1.4	1.4	1.4
4,6-Dinitro-2-methylphenol	1.5	1	1	1	1.8	1.4	1.4
2,4-Dinitrophenol	1	1	1	1	1.4	1.4	1.4
2,4-Dinitrotoluene	1	1	1.5	1.5	1.4	1.8	1.8
2,6-Dinitrotoluene	1	1	1.5	1.5	1.4	1.8	1.8
1,4-Dioxane	1	1	1	1	1.4	1.4	1.4
Dodecane	1	1	1	1	1.4	1.4	1.4
Endrin	1	1	1	1	1.4	1.4	1

UNCERTAINTY SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments			Adjusted Inherent Hazard by Medium		
		Air B	Surface Water C	Ground Water D	Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground Water G $\sqrt{A^2+D^2}$
Epichlorohydrin	1	1	1	1	1.4	1.4	1.4
Ethylbenzene	1	1	1	1	1.4	1.4	1.4
Fluorene	1.5	1	1	1	1.8	1.8	1.8
Fluorine (fluorides)	1	1	1	1	1.4	1.4	1.4
Formaldehyde	1	1	1	1	1.4	1.4	1.4
Hexachlorobenzene	1	1	1	1	1.4	1.4	1.4
Hexachlorobutadiene	1	1	1	1	1.4	1.4	1.4
Hexachlorocyclopentadiene	1	1	1	1	1.4	1.4	1.4
Hexachloroethane	1	1	1	1	1.4	1.4	1.4
Hexachlorophene	1	1	1	1	1.4	1.4	1.4
n-Hexane	1	1	1	1	1.4	1.4	1.4
Hydrazine	1	1	1	1	1.4	1.4	1.4
Hydrogen chloride	1	1	N/A	N/A	1.4	N/A	N/A
Hydrogen sulfide	1	1	N/A	N/A	1.4	N/A	N/A
Indeno(1,2,3-c,d)-pyrene	1	1	1	1	1.4	1.4	1.4
Isophorone	1	1	1	1	1.4	1.4	1.4
Lead	0.5	2	2	2	2.1	2.1	2.1
Maleic anhydride	1	1	1	1	1.4	1.4	1.4

UNCERTAINTY SCORES FOR 140 SUBSTANCES

		Exposure Adjustments			Adjusted Inherent Hazard by Medium		
Compound	Inherent Hazard A	Air B	Surface Water C	Ground Water D	Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground Water G $\sqrt{A^2+D^2}$
Mercury	1.5	1	1	2	1.8	1.8	2.5
Methomyl	1	1	1	1	1.4	1.4	1.4
Methyl bromide	1	1	1	1	1.4	1.4	1.4
Methyl chloride	1	1	1	1	1.4	1.4	1.4
Methyl ethyl ketone	1	1	1	1	1.4	1.4	1.4
Methyl hydrazine	1	1	1	1	1.4	1.4	1.4
Methyl parathion	1	1	1	1	1.4	1.4	
Naphthalene	1	1	1	1	1.4	1.4	1.4
2-Naphthylamine	1	1	1	1	1.4	1.4	1.4
Nickel	2	1.5	1.5	1.5	2.5	2.5	2.5
Nitrobenzene	1	1	1	1	1.4	1.4	1.4
Nitrogen oxides	1	1.5	N/A	N/A	1.8	N/A	N/A
2-Nitrophenol	1	1.5	1	1	1.8	1.4	1.4
4-Nitrophenol	1	1.5	1	1	1.8	1.4	1.4
N-Nitrosodimethylamine	1	1.5	1	1.5	1.8	1.4	1.8
N-Nitrosodiphenylamine	1	1.5	1	1	1.8	1.4	1.4
Octachlorostyrene	1.5	1	1	1	1.8	1.8	1.8
PCB-1016	1.5	1	1	1	1.8	1.8	1.8
PCB-1221	1.5	1	1	1	1.8	1.8	1.8

UNCERTAINTY SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments Air B	Surface Water C	Ground Water D	Adjusted Inherent Hazard by Medium Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground Water G $\sqrt{A^2+D^2}$
PCB-1232	1.5	1	1	1	1.8	1.8	1.8
PCB-1242	1.5	1	1	1	1.8	1.8	1.8
PCB-1248	1.5	1	1	1	1.8	1.8	1.8
PCB-1254	1.5	1	1	1	1.8	1.8	1.8
PCB-1260	1.5	1	1	1	1.8	1.8	1.8
Parathion	1	1.5	1	1	1.8	1.4	1.4
entachlorophenol	1	1	1	1	1.4	1.4	1.4
Phenanthrene	1.5	1	1	1	1.8	1.8	1.8
Phenol	1	1	1	1	1.4	1.4	1.4
Pyrene	1.5	1	1	1	1.8	1.8	1.8
Pyridine	1	1	1	1	1.4	1.4	1.4
Selenium	1.5	1.5	1.5	1.5	2.1	2.1	2.1
Silver	1	1	1	1	1.4	1.4	1.4
Sodium	1	1	1	1	1.4	1.4	1.4
Sulfur dioxide	1	1	N/A	N/A	1.4	N/A	N/A
2,3,7,8-Tetrachloro-dibenzo-p-dioxin	1	1	1	1	1.4	1.4	1.4
1,1,2,2-Tetrachloro-ethane	1	1	1	1	1.4	1.4	1.4
Tetrachloroethene	1	1	1	1	1.4	1.4	1.4

UNCERTAINTY SCORES FOR 140 SUBSTANCES

Compound	Inherent Hazard A	Exposure Adjustments Air B	Surface Water C	Ground Water D	Adjusted Inherent Hazard by Medium Air E $\sqrt{A^2+B^2}$	Surface Water F $\sqrt{A^2+C^2}$	Ground Water G $\sqrt{A^2+D^2}$
Thallium	1.5	1	1	1	1.8	1.8	1.8
Toluene	1	1	1	1	1.4	1.4	1.4
Toluene diamine	1	1	1	1	1.4	1.4	1.4
Toluene diisocyanate	1	1	1	1	1.4	1.4	1.4
o-Toluidine hydrochloride	1	1	1	1	1.4	1.4	1.4
Toxaphene	1	1.5	1	1	1.8	1.4	1.
1,2,4-Trichlorobenzene	1	1	1	1	1.4	1.4	1.
1,1,1-Trichloroethane	1	1	1	1	1.4	1.4	1.4
1,1,2-Trichloroethane	1	1	1	1	1.4	1.4	1.4
Trichloroethene	1	1	1	1	1.4	1.4	1.4
2,4,6-Trichlorophenol	1	1	1	1	1.4	1.4	1.4
Vanadium	2	1	1	1	2.2	2.2	2.2
Vinyl chloride	1	1	1	1	1.4	1.4	1.4
Zinc	1	1	1	1	1.4	1.4	1.4

APPENDIX VIII. SURROGATES AS SUBSTITUTES FOR PRINCIPAL ORGANIC HAZARDOUS CONSTITUENT VALIDATION OF INCINERATOR OPERATION

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Recent regulations on the incineration of hazardous wastes have focussed attention on the selection of Principal Organic Hazardous Constituent(s) (POHCs) and the use of the POHC concept as a means to validate incinerator performance. We discuss some of the problems inherent in such an approach and propose an alternative methodology involving the use of fluorinated compounds as surrogate markers for destruction efficiency. The factors that make these compounds suitable candidates are summarized. These factors include high thermal and chemical stability, non-toxicity and availability of sensitive detection methods. Various operational problems are considered. The compound SF_6 is commended as a suitable surrogate for indicating that required destruction removal efficiency of the incinerator for POHCs has been achieved.

Introduction

Present day regulations regarding the incineration of hazardous waste mixtures [1][1] involve the selection of the Principal Organic Hazardous Constituent (POHC) and the demonstration through test burns of its destruction removal efficiency (DRE) at the 99.99 percent level or better. The latter is expensive, and there are claims that the proposed methodology may be subject to many problems [2]. Furthermore, subsequent to the qualification test there are no means for determining whether the incinerator continues to operate properly. In this report, we call attention to the possibility of using tracer compounds, deliberately added to the waste mixture in small quantities, whose extent of decomposition can serve as a measure of proper incineration. This procedure is equivalent to the use of a surrogate for the principal organic hazardous constituent. However instead of dependence on the vagaries of the hazardous waste mixture yielding up a particular POHC, it will be possible to select compounds that are particularly compatible with a specific detection methodology. The general consequences are drastic simplifications of the entire validation procedure and considerably more accurate results. Real time or at least periodic determinations of DRE are possible. Indeed, one can visualize direct coupling of emission measurements with feed rates.

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[1] Figures in brackets indicate the literature references at the end of this paper.

We begin with some general considerations regarding properties of such tracers. This exposition leads to the identification of a variety of perfluorinated organics as candidate compounds. We will then demonstrate that these compounds have the required thermal stability features as well as favorable chromatographic and spectroscopic properties. Finally, we conclude by discussing a variety of operational problems and possible deficiences in the methodology.

General Considerations

Some of the desirable properties for molecules that are to serve as tracers include:

The compound in question should be considerably more stable than the POHC of the hazardous waste mixture. This property is mandated by the requirement for 99.99 percent destruction of the POHC. For practical purposes, we will be interested only in the addition of small quantities of the tracer to the reacting mixture. If this tracer were to be destroyed to the same or greater extent as the POHC, then even more severe demands would be placed on detection capabilities. On the other extreme, if a substance is too stable, then one has the equally undesirable situation where destruction of the POHC will result in trivially small reduction in tracer concentration. These constraints make it difficult for one compound to cover the entire range of possibilities. However, the possibility of obtaining several compounds with overlapping ranges of incinerabilities, spanning the entire scale, should be an achievable goal.

Having restricted the number of molecules that need to be considered, it is obvious that the ideal analytical methodology will be one with the greatest selectivity. This simple result can be placed in contrast to the situation with POHCs where one is forced to use the most general detection technology with all the attendant problems and cost. On this basis, infrared absorption with a laser source represents a particularly attractive possibility. Such a system permits real time monitoring of the behavior of the characteristics of the incineration system. Alternatively, gas chromatography with columns and detectors specific to the surrogate can also fill such a need.

Finally, there are several obvious and necessary properties, low cost, non-toxicity, minimal corrosion problems and absence from any possible hazardous waste mixture.

These constraints are severely limiting. They lead inescapably to the conclusion that perfluorinated compounds represent optimum candidates. Such compounds absorb very strongly in the infrared. Special columns are required for gas chromatographic separations. Perfluorinated compounds are extraordinarily sensitive to electron capture detection, are relatively simple to make and are may be found in extensive amounts in hazardous waste mixtures. The combustion product HF does represent a possible corrosion problem. It is expected that the small amounts formed will not cause noticeable effects.

Incinerability

In an earlier report [3] we have characterized the chemical processes that control the destruction processes in an incinerator in terms of a variety of elementary processes. These include unimolecular decomposition and bimolecular processes involving radical attack on the hazardous waste. The fundamental relation is

$$\frac{-d(Hz)}{dt} = k_{uni}\,(Hz) + \sum_{i}^{n} k_{bi}\,(R_i)\,(Hz)$$

where k_{uni} and k_{bi} are the unimolecular and bimolecular rate constants, and R_i is an attacking radical specie. These rate constants have fundamental significance in the sense that they are an intrinsic property of the molecule(s) in question and thus can be used in all contexts. They are different than rates used in process applications which are of great utility in process optimization but are difficult to use in other contexts. The general picture in terms of physical variables usually considered in hazardous waste incineration - wide ranging temperatures (ambient to flame conditions) and residence times in the 1 second range, is that of decomposition of the more unstable compounds by unimolecular mechanisms at the lower temperatures. The subject to attack by OH radicals and decompose via a bimolecular mechanism. Implicit for the latter process to occur is the assumption that OH and indeed other small radicals O, H are present in equilibrium concentration [3]. Such an approach, taken in conjunction with the existing data base, permits the establishment of a rank ordering of substances with regard to incinerability. We note in passing that our ordering is radically different from that proposed by EPA which is based on the heat of combustion. Nevertheless the chemical kinetic scale does correspond to experience and is in striking contrast to predictions based on heat of combustion. The latter predicts for example, that explosives such as nitroglycerine are more difficult to destroy than aromatic compounds such as benzene [4].

We now consider the following compounds, CF_4, C_2F_6, C_3F_8, C_4F_{10}, CF_3Cl and SF_6 as candidate tracers. We begin by analyzing the bimolecular processes. For the case of OH attack, note that HO-X bonds are relatively weak. For HO-Cl it is possible to estimate a value in the 50-70 kcal (4.184 joules = 1 calorie) range [5]. However, the bond strength of the C-F, C-Cl and S-F bonds are in the 129, 86 and 95 kcal range respectively [5]. The consequence is that OH abstraction is a highly endothermic process. This result is in striking contrast to hydrogen atom abstraction from hydrocarbons where the resulting H-OH bond is 117 kcal and the overall reaction is highly exothermic. In terms of rates, the consequence is that, compared to hydrogen abstraction processes, the dehalogenation reaction is many orders of magnitude smaller. A similar argument can be made for oxygen atom attack.

Next consider hydrogen atom attack which is an almost thermally neutral reaction with respect to abstraction from the C-F bond and strongly exothermic for the S-F and C-Cl abstraction process. Nevertheless, published results give [7].

$$k(H + SF_6 \rightarrow HF + SF_5) = 10^{15} \exp(-44000/RT) cm^3/mol\text{-}s$$

and

$$k(H + CF_4 \rightarrow HF + CF_3) = 10^{15.3} \exp(-30000/RT) cm^3/mol\text{-}s$$

Although the A-factors (pre-exponential term) appear to be high, the measurements are at high temperature and the consequence of the high activation energy is to make the rates of these processes very small compared to the abstraction of H or Cl atoms from a hydrocarbon backbone. Certainly the rate will not be faster. The rate expression for Cl abstraction from CF_3Cl is [6].

$$k(H + CF_3Cl \rightarrow CF_3 + HCl) = 10^{13.2} \exp(-8100/RT) cm^3/mol\text{-}s$$

This rate is very close to the comparable abstraction from methyl chloride but much slower than most H abstraction processes. Furthermore, we recall that OH is present (except in fuel-rich systems) in higher concentrations than hydrogen atoms; abstraction processes for the latter are in general slower than those with OH present. Note that large polyatomic organic radicals such as CH_3 are vastly less effective in abstraction processes than inorganic species such as OH, O or H. Thus, for these tracers under incineration conditions, bimolecular decomposition processes will be extremely slow as compared with most hazardous wastes. As a result of these considerations, we make the assumption that the most important mode of decomposition is by unimolecular bond breaking processes.

We have listed in table 1 a variety of information dealing with the unimolecular decomposition characteristics of the six candidate tracers. These data involve the bond dissociation energy, defined as ΔH (reaction) at 298 K, an estimated rate expression for bond cleavage and the temperatures required for 99.99 percent, 99 percent, and 63.4 percent destruction. The first number is the familiar four nines destruction limit. However as noted earlier the determination of 0.01 percent (100 ppm) of a substance present in trace quantities may well make inordinate demands on the analytical methodology. On the other hand, as will be shown subsequently, the very favorable analytical characteristics of these compounds allows them to be detected at very low levels. However, the data in table 1 indicate that tracers having lower destruction efficiencies will be more suitable for achieving the goal of using surrogates to calibrate DRE. These numbers were derived from the integrated equation for unimolecular decomposition

rate constant x time = ln [initial concentration/final concentration]

with time equal to one second. Data are included in table 1 for the temperature range of 1100 to 1400 K for all except perfluorinated methane which spans the range of 1800 to 2000 K. In general, there should be no problem in finding other compounds that will be useful at progressively lower temperatures. One suspects that various fluorinated aromatic and other unsaturated compounds can be found to cover the 1400-1800 K gap.

Note that the rate expressions shown in table 1 are subject to some uncertainty. There has been a direct determination of SF_6 decomposition [7], and Lyman [8] has recently re-interpreted the data. The numbers shown in table 1 are directly taken from the latter work. The results for perfluorinated ethane were derived from the rate of combination of perfluorinated methyl radicals and the thermochemistry of the reactions. The result we obtained is more than a factor of 10 slower than a measured determination reported about fifteen years ago [9]. We believe that the interpretation of the earlier data is incorrect.

For the other compounds, the pre-exponential factors have been estimated by analogy. For example, we use the same A-factor for CF_3Cl decomposition as that experimentally determined for CF_3Br. [10] The bond energies are fairly well established. We have also taken into consideration pressure effects using well established techniques (11).

An examination of the data in table 1 suggests that the temperature range over which a particular molecule is effective as a tracer is limited. Hence, the necessity for a number of such compounds. Presumably, for any mixture of hazardous organic wastes, convenience will dictate a temperature that is not substantially larger than that which will yield the required four-nines destruction of the principal organic hazardous contaminant. For most of the organics in the EPA listing of hazardous compounds, these proposed surrogate substances will fulfill this role.

A question requiring consideration is whether any of these tracers are more stable than possible products of incomplete combustion such as hexachlorobenzene and dioxin. There is considerable justification [12] for the usual assumption that such compounds along with the PCBs are among the most recalcitrant of organics with respect to incineration. Some results are summarized in table 2: Apparently SF_6, C_2F_6 and CF_3Cl are candidate tracers for assuring destruction of hexachlorobenzene and inferentially the PCBs, since the rate of CCl bond cleavage in these systems should be comparable. Similarly, C_3F_8 and C_4F_{10} can also serve this role for "dioxin-like" compounds.

Perfluoromethane is obviously much too stable for the present purposes. Substantial destruction of this compound requires temperatures hundreds of degrees above those necessary for the destruction of all organic hazardous wastes on the basis of chemical considerations. Nevertheless, its very stability, suggesting that it will survive the usual incinerator environment can be an extremely useful property as will be discussed in a subsequent section. Clearly there are compounds whose properties make them very suitable as surrogates for four-nines removal of hazardous organic waste. However, a cautionary word is necessary. Many of the properties have been estimated and are subject to some uncertainty. Experimental verification is thus very important.

Detection

We next consider the methodology for the detection and quantitation of dilute amounts of these candidate tracers. Specifically, we will examine analysis by gas chromatography and infrared spectroscopy. With respect to the former, there is a vast literature (13) on the resolution of fluorinated compounds. For stationary phases such as charcoal or silicone oil, separation can be achieved through boiling point differences. With ordinary hydrocarbon substrates, perfluorinated compounds are barely retained since they have very high activity coefficients. Taken together with the fact that these compounds all have very low boiling points, simple unambiguous identification by retention time can be readily accomplished. Furthermore, electron capture detectors are extremely sensitive to such compounds. Such detecters are completely insensitive to the light inorganics and hydrocarbons that are most likely to create interferences. The sensitivity limits appear to be in the part-per-billion or lower range. Thus, it is clearly feasible to take a "grab sample" or samples and make a direct measurement of tracer concentrations at any time or times during the course of an incineration burn. This procedure is considerably simpler than the more complex and expensive analytical methodology that is absolutely necessary for the determination of the four nines destruction of a selected Principle Organic Hazardous Constituent. Particular attention is called to the practical possibility of making replicate measurements on a daily or even hourly basis. This activity would help to ensure that statistically significant results are being achieved. Constant monitoring of incinerator performance is even a possibility. Finally, these candidate surrogate compounds have been utilized as atmospheric tracers in the context of air pollution problems [14]. The overall methodology is thus of the order of 15 to 20 years old.

Next consider infrared spectroscopy for the detection of the listed surrogates. All of these compounds have one or more strong absorption bands in the infrared [15-18]. There is, however, the possibility that one or more of the POHCs or other combustion products might have overlapping absorptions at a given wavelength. This problem is significantly reduced because of the high degree of wavelength selectivity obtainable in infrared laser probing of the gas mixture. Thus this analytical method is most advantageous. Table III shows reported representative maximum absorption coefficients for some of the candidate tracers at wavelengths corresponding to CO_2 gas laser emission lines. In the cases of C_2F_6, C_3F_8 and n-C_4F_{10}, considerably more data regarding laser line coincidences is needed at the present time. The absorption coefficients are such that limiting detection sensitivities are commonly as low as approximately 10 ppb and in the case of SF_6, ppt detection is a possibility. Careful standardization/calibration of measurements may be necessary due to variations associated with laser operating characteristics and the variation of the absorption coefficient with pressure and temperature. The technological requirements for these measurements are straightforward and well within the state of the art. Reliable, low power CO_2 laser sources are commercially available, and when used in conjunction with photo-acoustic detection, provide another example of a powerful approach to the problem of monitoring tracer concentrations. The literature is replete with other examples of laser optical monitoring techniques which have ready application here [19]. Appropriate signal averaging, modulation and dual wavelength referencing methods in conjunction with particulate filtering, where necessary, can provide for virtually real-time, continuous monitoring of statistically representative samples of the combustion effluent stream.

Some work remains to be accomplished in terms of acquisition of spectroscopic data for determination of high temperature absorption coefficients of the tracer species if real time, high temperature in situ monitoring of the incinerator effluent stream is desired. However, for most applications, one may alternatively wish to consider thermally quenching the effluent stream and making measurements at room temperature where more is known about the absorption properties of most of these gases. This procedure may somewhat reduce the real time nature of the measurement to a short time-averaged value. But results will probably not be impaired in any serious manner. Most commercial incinerator equipment control variables are likely to require even longer times for modification if adjustments in the incineration operation are required. In this respect, for many applications, flow stream diversion and grab sampling may be acceptable.

Practical Aspects

In the earlier sections, we focussed on the specific properties of molecules which make them suitable as surrogates for the Principal Organic Hazardous Constituents and indeed as Products of Incomplete Combustion. We will deal with now a variety of operational problems which are of key importance in field operations. First, consider the appropriate quantities of tracers that should be used. With detection limits in the 1 to 10 ppb range, and assuming a dilution factor of 50 during combustion, the concentration of the tracer e.g., SF_6, in the input waste stream must be of the order of 500 to 5000 ppm if four-nines destruction of the tracer is necessary. On the other hand, if the tracer is sufficiently stable , then in the most favorable situation one can start at levels in the input waste stream as low as 30 to 300 ppb. We expect that input waste stream tracer concentrations in the 1-20 ppm level will satisfy all requirements. Thus, for a typical hazardous waste operation that incinerates on the order of 75,000 liters/day, the use of $\approx$ 0.5-5 kg/day of tracers will be required. Most of the candidate compounds are available from standard supply houses. For the fluorinated compounds, costs are of the order $2.00-$10.00 per kg.

The cost of analytical instrumentation can be compared to the gc-ms that is usually required for the determination of four-nines destruction of the principal organic hazardous component. For the case of gas chromatography with electron capture detection, the cost is about ten times less. For infrared detection the factor will be of the order of 3 to 4 less. Additional cost benefits derive from the one pass analysis as opposed to the necessity of collecting and pre-concentrating samples for gc-ms analysis. Finally, by concentrating on a few surrogates as opposed to the entire EPA listing of hazardous chemicals, one anticipates additional saving and improved efficiency and accuracy resulting from the accumulated experience of carrying out the same procedure by all operators.

An important issue in using this technique is the proper introduction of the tracer into the incinerator. Obviously, the preferred method of introduction should be through the waste stream. Since we are interested in a quantitative measure of the extent of decomposition of the tracer, constant composition with respect to air and waste streams must be maintained. Proper blending of surrogate and waste streams may be a serious problem. We suspect that instead of direct mixing in the waste stream prior to injection, the best practical procedure will be to inject in close proximity to the latter.

An alternative possibility is to use a pair of tracers, one of the which is completely stable under incinerator conditions and the other less stable and thus subject to decomposition. If relative concentrations are known, then the ratio of compounds left after passage through the incinerator will give a very high accuracy value for the extent of decomposition of the surrogate. On the basis of our earlier discussion, CF_4 would seem to be an ideal candidate for the stable internal standard. There are many advantages to this mode of operation: Blending requirements can be significantly relaxed. Absolute concentration levels need not be precisely maintained. One can in fact visualize periodic injection and analysis which would have great advantages with respect to material and operational costs.

A drawback to this technique may arise from the high volatility of the surrogates. There is no question that any substance that is vaporized upon introduction into the incinerator environment will experience situations exactly akin to that faced by the tracers. Thus, the surrogate deals specifically with gas phase substances. On the other hand, a non-volatile hazardous material or one that is strongly absorbed onto a particulate effluent may experience situations that are different than that faced by the tracer. We are uncertain about the importance of such effects but suspect that in systems having a great deal of particulate emission, departures from ideality will be most serious. These problems are discussed in some detail in a recent report [20]. There may well be a specific particulate concentration level above which tracer results begin to deviate. However, it is possible that the present particulate standards called for via regulations will be sufficient. Obviously, experimental work on this and other issues raised in the course of this paper is needed if this methodology is to be appropriately applied.

Conclusions

If, as suggested by current regulations, hazardous organic wastes can be ranked according to their incinerability, then it should be possible to select a number of tracer compounds that can act as surrogates for the Principal Organic Hazardous Constituent. Such an approach can lead to simplifications and uniformities in analytical methodologies and bring about important cost savings as well as increased reliability. A number of fluorinated compounds have been selected as possible surrogates and the rationale for such a choice is indicated in terms of kinetic properties of these compounds under incineration conditions. Gas chromatographic and infrared detection appear to be the analytical methods of choice; detection limits in the ppb range appear to be possible. Some potential operational problems are discussed; the need for experimental verification is stressed.

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Table 1. Properties of Candidate Tracers

	Bond Energies (weakest bond) (kcal)		Rate Expression (sec^{-1})	Temperature (Destruction Limits) Units (K)		
				99.99%	99%	*63.4%
CF_4	(C-F)	129	$10^{14.5}$ exp(-125000/RT)	2023	1976	1890
SF_6	(S-F)	93	$10^{14.5}$ exp(-92000/RT)	1488	1457	1390
CF_3Cl	(C-Cl)	87	$10^{14.5}$ exp(-85000/RT)	1375	1345	1285
C_2F_6	(C-C)	97	10^{16} exp(-94500/RT)	1375	1345	1292
C_3F_8	(C-C)	91	$10^{16.3}$ exp(-89000/RT)	1268	1245	1195
C_4F_{10}	(C-C)	89	$10^{16.3}$ exp(-87000/RT)	1242	1218	1165

* "1/e" destruction time.

Table 2. Temperature for Decomposition of Recalcitrant Hazardous Wastes

Hexachlorobenzene

k_{bi} (OH + hexachlorobenzene) $\sim 10^{11}$ cc/mol-s; with OH = $10^{-4.7}$ exp(-35000/RT)mol/cm^3

k_u (hexachlorobenzene) = 10^{16} exp(-92000/RT)

99.99% destruction at 1323 K in 1 second

Dioxin

k_{bi} (OH + dioxin) $\sim 3 \times 10^{11}$ cc/mol-s; with OH = $10^{-4.7}$ exp(-35000/RT)mol/cm^3

k(dioxin) = 3×10^{15} exp (-80000/RT)

99.99% destruction at 1194 K in 1 second

Table 3. Infrared Spectroscopic Properties of Some Candidate Tracers

Compounds	Absorption coeff. ($atm^{-1}cm^{-1}$)	Position	Estimated minimum detection limit (absorption)	
SF_6	304	944.1948	10 ppb	16,17
CF_4	0.4	1073.2785	8 ppm	18
CF_3Cl	5	1084.6325	6 ppm	19

APPENDIX IX. RESEARCH APPROACHES FOR DETERMINING COMPATIBILITY OF POLYMERIC LINER MATERIALS WITH HAZARDOUS WASTES[1]

A successful polymeric liner must retain its mechanical and barrier properties in the presence of permanent contact with water containing diluted hydrophilic or suspended hydrophobic substances or solid particles. The first two kinds of material may diffuse into the polymer and eventually transform into a soft rubbery material or even disintegrate it by chemical attack. Solid particles may abrade the polymer surface and thus gradually degrade the useful properties of the hydrophilic material.

A hydrophobic polymer would reject the majority of the hydrophilic material. But the active oxygen containing compounds could oxidize and hence disintegrate the polymer. The hydrophobic character of a part of the dissolved molecules, which are prevailingly hydrophilic since they are dissolved in water, may permit partial diffusion into the polymer. The polymer may be adversely affected in a way similar to although less rapid than that of the hydrophobic suspended material. The hydrophobic molecule of the suspended liquid particles may diffuse into the polymer and depress its glass transition temperature so much that the mechanical strength of the swollen polymer is no longer adequate. The oxidative and other types of chemical reactions are the same as formerly mentioned with hydrophilic substances although in this case the action may extend more rapidly to deeper regions of the polymer because the molecular diffusion of hydrophobic material in the polymer may be substantially higher.

Hence, careful consideration is needed for the selection of the proper polymeric materials to be used as a liner for a given industrial or any other kind of effluent waste. Three types of action have to be considered: 1) diffusion with the ensuing lowering of the glass transition of the swollen polymer; 2) oxidative or any other type of chemical action which may lead to the disintegration or at least softening of the polymer; and 3) mechanical stress or abrasion. The effects are not independent. They may be strongly synergistic. As a polymer softens it becomes much less abrasion resistant. The softened or disintegrated material as a rule permits a much faster diffusion of penetrants than the unaffected material.

The first two effects may be studied in an apparatus which permits the investigation of the mechanical properties of the polymer after extended contact with either flowing or standing liquid containing dissolved hydrophilic or suspended hydrophobic liquid component. The design of suitable apparatuses should permit simultaneous measurements of diffusion and the effects of diffusants on mechanical properties. The optimal specimen geometry should take account of the dependence of the penetration depth on the square root of time and that softening and chemical reaction effects mainly depend on the local concentration of the penetrant. Hence, the effects are much faster and easier to observe in thin films particularly if the diffusion can proceed from both sides of the film.

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[1] Prepared by Polymer Science and Standards Division, National Bureau of Standards.

The abrasion of polymeric liner materials can be investigated through a simulation of flow patterns. Abrasion is a purely mechanical effect of a liquid containing solid particles. It can be substantially enhanced by swelling or partial disintegration of the polymer.

In principle, the effects of the gaseous environment on the mechanical properties of thin films can be investigated using an instrument-designed and built at NBS-which permits simultaneous measurements of sorption, diffusivity, strain, and stress. The interdependence of the first two with the last two effects facilitates the study of sorbed vapor on the mechanical properties of the film and on the rate of the effect.

A film that has sorbed a vapor, gas, or liquid will also have a lower glass transition temperature and, hence, will become rubbery. In such a softened state, the imposition of a strain will cause the stress to decrease and stress relaxation rate to be enhanced with some concurrent effect on sorption and diffusivity. The time dependence of the modulus or rigidity of the film during diffusion may be determined from the stress and the imposed strain. Damage to the film may be ascertained by comparing the modulus of the sorbed or desorbed film to that of the dry film. Hence, stress relaxation may be used to indicate some degree of compatibility of penetrant and film. Changes in temperature also influence the modulus and diffusivity and, therefore, may enhance damage or degradation of the film. The instrument mentioned above may be used to monitor the lowering of the modulus of the film at different temperatures and different concentrations of penetrant in the gas or vapor phase. In certain cases, the instrument may be used to determine simultaneously the uptake of the penetrant.

APPENDIX X. REGULATORY CONTROL OF HAZARDOUS WASTE LEVEL

R. T. Matthews

This presentation presents a snapshot survey of the States in controlling hazardous waste management as of September 28, 1982.

OUTLINE

Introductory Remarks: Status of the authorization of State programs under Subtitle C, RCRA

- Impact of the reduction in federal funding on State hazardous waste management programs
- State planning and administration approaches
- Institutional and organizational structures

Regulatory Similarities and Differences at the State Level Pertaining to

- Waste Definition and Criteria
- Waste Exclusions/Exceptions
- Financial Requirements, Penalties, Licenses

State Measurements Needs Addressing:

- State laboratory capabilities
- Analytical requirements and administrative procedures

Federal, State Priorities in Terms Of

- State Authorization
- Permits: TSDF Facilities
- Degree of Hazard
- Siting

Summary and Outlook

REDUCTION IN FEDERAL FUNDING AND ITS IMPACT ON STATE HAZARDOUS WASTE MANAGEMENT PROGRAMS

Subtitle C, RCRA provided substantial levels of authorized funding to those States undertaking the federal hazardous waste management program. In the previous administration, the EPA Assistant Administrator for Water and Waste Management assured the States that Federal funding for State solid and hazardous waste management programs would be available for five years, albeit on a scale decreasing to zero. To date the appropriated funds available for State hazardous waste management grants have not been at authorized levels. Moreover, Subtitle D funds for solid waste management were terminated September 1981. Currently EPA has encouraged the States to adopt a user fee system in order to become self-supporting in both solid and hazardous waste management.

For example, with FY 79 budget authorization provided for $134.5M for Subtitle C activities, only $56.9M was dispensed to the States with $11.2M earmarked for State solid waste management activities, $15M for the President's resource recovery urban grants program, and $15M for Subtitle C programs. In FY 1980, EPA allocated $18.6M Subtitle C, $10M for Subtitle D, and $10M for resource recovery planning. The States have testified that federal assistance must be continued and increased under Subtitle C to $60M for FY 1983, $80M for FY 1984, and $100M for FY 1985 in order to assure State-to-State program consistency is achieved as well as to provide for protection of public health and the environment. In contrast, the current federal budget for Subtitle C calls for 16 percent reduction from $41.7M to $35.1M.

EPA's policy strategy document _Coping With The FY 1983 Budget Reductions_ states that the "true cost of implementing Phase II of the hazardous waste management program is unknown. The risk of States refusing or returning the Hazardous Waste and Underground Injection Control Program" exists. Indeed ten States have indicated that withdrawal or consideration of withdrawal from the national hazardous waste management program is likely should adequate federal funding not be forthcoming. For these States remaining in the federal system, funding assistance is recognized as severely insufficient.

Since 1977, State grants have been allocated according to a formula heavily weighing population and geographic criteria. With the promulgation of the full set of Subtitle C regulations, the dispersal of funds will adhere to the criteria set forth in the statute, Section 3011:

o Volume of wastes generated, transported, treated, stored and disposed of in the State;

o Extent to which such wastes impact on public health and the environment;

o Whether or not the State hazardous waste planning addresses inactive hazardous waste storage, treatment and disposal facilities;

o Other factors deemed appropriate by EPA Assistant Administrator.

Some States either have no facilities within their respective borders, and/or are net exporters of hazardous waste. Therefore, such States could anticipate a reduction in federal grant monies while at the same time striving to upgrade programs and enforcement in order to obtain interim or final authorization.

States are facing a financial dilemma--they have undertaken commencement of, or continuation of, hazardous waste management program in accord with federal requirements while at the same time facing a total loss of solid waste federal funding and a substantial reduction of federal hazardous waste funding. State regulatory agencies are trying to justify maintaining adherence to federal requirements for consistency and obtaining funding from other sources. Without stable sources and levels of funding State directors will have difficulty in maintaining adequate staff and resources to issue permits and to assure equitable enforcement. Consequently, many States are following EPA's recommendation and imposing user fees. Examples of the approaches taken are herein highlighted:

Louisiana: The Department of Natural Resources, Hazardous Waste Division is supported by a fee system delineated in the State plan consisting of:

- One-time application fee is charged to cover application, evaluation and other related program costs. There is no fee for applications for minor modifications.

  The applicant is required to calculate his appropriate applications fee according to the schedule included in the permit application form:

Item	Fee
Site analysis, per acre	$ 250
Process and plan analysis	1,000
Facility analysis, per facility	500
Management/financial analysis	1,000

- Permit maintenance fees are charged to cover costs of administration and other program costs.

- Annual disposal fees per site

Commercial, off-site	25,000
Non-commercial, off-site	5,000
Non-commercial, off-site and non-continuous	5,000
On-site	2,500

  Excess funds over program cost generated by annual fee shall be credited to the following year's budget.

- In addition, a $1,500 fee per facility is billed bi-annually to support the manifest and emergency response sections.

o A waste disposal fee is based on volume of waste, and bills are sent on a quarterly basis. Generators of hazardous waste are not billed. The fee structure is:

less than 1,000 tons	$ 1,000
1,000 tons to 10,000 tons	2,000
10,000 tons to 100,000 tons	3,000
100,000 tons to 1M tons	4,000
More than 1M tons	5,000

Oklahoma: The Industrial Waste Division, Department of Health is pursuing several avenues to secure the fiscal resources to support its staff. The division had assumed in its budgets for FY 1982 and FY 1983 a 20 percent increase in Federal funding each year. Currently the State's portion of the division's budget is provided for in the department's general appropriation. While this appropriation should increase in FY 1983, additional funds will be required. The shortfall of funds must come from State sources. Therefore, the division has adopted a fee system for hazardous waste generators, transporters, and treatment, storage, and disposal facilities. The goal is the achievement of self-supporting program.

New York: The Department of Environmental Conservation considered a fee system but does not expect those fees, if collected, to replace all needed federal funds.

Programmatic Consequences: The consequences of federal funding cutbacks are apparent in the solid waste management area. For example, the national open dump inventory is not complete and, hence, States will have difficulty in bringing those sites determined under State law to be open dumps into compliance or to closure. Furthermore, the States most likely will not complete the inventory. The situation has developed that many of the sites inventoried and determined to be dumps, as well as those not inventoried, may become repositories for hazardous wastes. The resultant regulatory burden on the State's hazardous waste management program is predictable.

State hazardous waste management activities such as site investigation, litigation, and remediation regarding inactive hazardous waste sites are not eligible for application of federal grant funds.

Since the State agencies support concurrently both solid and hazardous waste management programs, the total amounts to be generated should be calculated accordingly. States are, and will continue to be seeking legislative authority to impose funding systems to support existing solid and hazardous waste management programs. These funding sources may include, but are certainly not limited to, permit fees, generation and/or disposal charges based on volume and/or waste type, spill contingency funds, funds for the closure and postclosure care of treatment and disposal facilities. Some States have indicated a concern for placement of the funding burden on small generators, or upon a limited number of generators.

Therefore, the identification of generators and disposal site operations capable of supporting the fee system--such as federal facilities--requires consideration and examination.

Planning and Administration: Under Subtitle C, Section 3006, EPA in consultation with the States, set forth guidelines by which a State may receive authorization to administer the federal hazardous waste management program. Early on, the States identified as an issue the distinction between authorization as outlined in RCRA as opposed to delegation as provided in the Clean Air Act, Clean Water Act, and the Safe Drinking Water Act. Under RCRA, the States programs are authorized in lieu of the federal hazardous waste management program. Therefore, the State's goals are primary and the State's unique characteristics of administration and planning are retained.

The State's program is authorized if two conditions are met: 1) the program is equivalent to federal standards and regulations; and 2) consistent with other authorized State programs. The equivalency debate between EPA and the States during the authorization process has sometimes been heated. EPA's interpretation became a question of the State program being identical to, rather than equivalent to, the federal program. According to State spokesmen, EPA headquarters, in the past has not been able to judge substantial equivalence and so has not been able to direct the federal regions regarding the definition of the term. To data EPA, according to the States, has interpreted equivalent to mean identical, while the States insists on the interpretation equal in effect. There has resulted considerable disparity between regions as to which State programs are judged equivalent.

There is general agreement, however, that the federal regulations are a minimum requirement and the States are free to set more stringent standards. An important constraint on the latter action is that a State may not impose any requirement that might interfere with the free movement of hazardous wastes across State boundaries when the waste is destined for a storage, treatment, or disposal facility holding a RCRA permit.

States receive authorization in two stages: interim and final. A substantially equivalent State program must meet the following criteria for interim authorization:

- control as nearly an identical universe of waste as is controlled by the federal program;
- cover all types of hazardous waste facilities in the State;
- be based on standards that provide substantially the same degree of human health and environmental protection as do the federal standards; and
- be administered through procedures that are substantially equivalent to procedures in the federal program.

Because EPA has promulgated the Section 3004 TSDF standards in several stages, the agency determined that States may apply for and receive interim authorization in stages. Phase I, interim authorization allows States to administer programs in lieu of, and corresponding to, that portion of the federal program which covers identification and listing of hazardous waste (40 CFR Part 261) and interim status standards for hazardous waste treatment, storage, and disposal facilities (40 CRF Parts 262, 263). EPA, however, handled the granting of interim status for these TSDF facilities directly.

Phase II, interim authorization allows the State to administer permit programs for hazardous waste treatment, storage, and disposal facilities; the permits must apply standards substantially equivalent to the federal, Part 264, standards. In short, as each component of the Part 264 standards is promulgated, EPA announces in the Federal Register notice that the States may apply for interim authorization for that component as well as previously promulgated components.

This interim authorization is effective for 24 months beginning six months after the promulgation data of the regulation. A State may apply for interim authorization during Phase I and later amend its application in accordance with Phase II requirements. If a State does not apply for and receive interim authorization, EPA must administer a federal hazardous waste program in that State. In the latter case, the federal and State programs co-exist.

A State need not apply for and receive interim authorization in order to be eligible for final authorization. States may apply for final authorization anytime after the beginning of Phase II interim authorization. Again, if a State does not obtain final authorization, EPA must administer a federal hazardous waste program in the State. As in interim authorization, both the State program and the final federal program co-exist.

Although EPA required 3.5 years to develop and to promulgate the rules and regulations for Subtitle C (May 1980), Phase I interim authorization could be granted to each State only if the applications was approved by EPA prior to November 19, 1980. In the States' view, this six month period was an extremely short time frame to develop an application on which detailed managerial, technical, and personnel decisions had to be made. Moreover, draft EPA guidance on applying for interim authorization was not available to the States until July 1980, with further guidance coming to the States in August 1980. This restrictive time frame made it all but impossible for States to receive interim authorization without directly adopting all the federal regulations to that date by reference.

A 31 State poll was conducted to determine the problems the States experienced during the interim authorization application process. Of the 31, 17 States had applied directly for interim authorization, 12 States had applied for cooperative agreements prior to interim authorization, and two States had applied for both at the same time. The review time varied from one to six months. The length of time for review by EPA was directly proportional to the extent that the State had a hazardous waste program in place. The States which adopted the federal regulations verbatim had the least trouble; the States with a more complex hazardous waste program found great difficulty in meeting the equivalency provisions of the statute.

EPA encouraged States which did not seek interim authorization to reach a cooperative agreement with the agency for all or a portion of the federal program. In the development of such arrangements, the assignment of the responsibilities for major elements of the program were not clearly defined. In most cases, work was to be performed in a joint effort by EPA regional personnel and State personnel. However, EPA generally ended up in a supervisory capacity with State personnel actually performing the inspection work. EPA, however, retained the final authority in any determination for enforcement purposes.

In summary, according to the States' reports, the submittal of draft and final interim authorization applications and cooperative agreements was a frustrating, time-consuming experience. A short turn around time, lack of EPA guidance, and the complexity of the federal regulations, added to the burden of the assumption of the program.

States opted for framing the hazardous waste management programs in three ways:

- In some States, the hazardous waste management program must be consistent and equivalent with the federal program (e.g., West Virginia).
- In other States, the law requires that the program be no more stringent than the federal program (e.g., Colorado).
- In the remaining States, statutory language requires that State programs be at least as strict as the federal program.

Consequently, the legislative and regulatory approaches employed by the States are different despite the fact that most States have interim authorization and many (EPA estimates 40) will receive final authorization. The issue of State-to-State consistency must be dealt with in the final authorization process.

The permit applicant would do well to be cognizant of the specific State's difficulty in obtaining authorization and to be aware of the particular mind set at work in the State. In order to appreciate the differences, a capsule presentation of a few selected State hazardous waste management programs is in order:

Institutional and Organizational Structures: Three distinct institutional and organizational structures are prevalent in solid and hazardous waste management:

- Single State health and/or environmental protection agency with one division being charged with solid and hazardous waste management;
- Single State health and/or environmental protection agency with separate divisions for solid and hazardous waste management;
- Two separate regulatory agencies for solid and hazardous waste management.

For the latter case, examples are the States of Texas and California.

Pennsylvania: The Department of Environmental Resources is the agency responsible in the Commonwealth for administration of all statutory responsibilities and programs related to the protection of the Commonwealth's air, water and land resources. The Bureau of Solid Waste Management is the entity within the Department with primary responsibility for implementation of Pennsylvania's solid waste program. The term "solid waste" includes hazardous waste, residual waste (non-hazardous industrial waste), and municipal waste.

The Bureau of Solid Waste Management administers and enforces a comprehensive State hazardous waste program in conformance with requirements of Subtitle C, RCRA. Administration and enforcement of this program is conducted according to the provisions of the Pennsylvania "Solid Waste Management Act" of 1980 (Act 97, effective September 1980) and "Chapter 75, Solid Waste Management Rules and Regulations."

Rules and regulations regarding the criteria and listing of hazardous waste were promulgated on July 15, 1980 and became effective August 2, 1980. The remainder of the hazardous waste regulations were proposed to the Environmental Quality Board on September 17, 1980, and became effective on November 18, 1980. Upon the effective date, all rules and regulations became effective and enforceable; compliance with such rules and regulations is required of all existing facilities.

As part of the Department of Environmental Resources' Deputate for Environmental Protection, the Bureau has a structure which places the primary emphasis on regional control and responsibility, with a central staff that provides technical and policy guidance, assistance, and support to the regions.

There are seven Regional Solid Waste Management Offices throughout the Commonwealth. Each has a specific geographic area for which it is responsible. Each office consists of two functional sections--Operations and Facilities--under the direction of a Regional Solid Waste Manager. The facilities sections have two major tasks to perform: 1) to review and issue permits to new solid waste facilities; and 2) to provide technical services to the regional staff in such areas as engineering, soils, and geology. At the regional level, the operations section's primary concerns are the enforcement of solid waste management standards, monitoring and inspection of solid waste facilities, and investigation of complaints involving violations of State solid waste laws and regulations.

Louisiana: The passage of Act 334 in 1978 authorized the establishment of a comprehensive waste control program under the primary auspices of the Department of Natural Resources (DNR). The statute also provided for the promulgation of regulations and a Hazardous Waste Management Plan (HWMP). In 1979, the program was amended by Act 449, the Louisiana Environmental Affairs Act (LEAA), in order to bring the program within the reorganization of the State's environmental agencies. Under the guidance of the Environmental Control Commission, DRN retained the primary authority for the administration of Louisiana's hazardous waste management program. The Department of Natural Resources Office of Environmental Affairs is the lead agency of Louisiana's hazardous waste management program. The Division of Hazardous Waste within OEA bears the responsibility for implementing the comprehensive hazardous waste regulatory program, which incorporates the mandatory provisions of RCRA, Subtitle C.

Among the powers and duties of the office are: 1) the holding of hearings; 2) the issuance of orders and determinations including emergency cease and desist; 3) the advising, consultation, and cooperation with other State agencies and political subdivisions, and federal government, other States, interstate agencies, interest groups; 4) the encouragement and/or conduct of studies, investigations, and research; 5) the collection and dissemination of environmental protection information; 6) the receipt and budgeting through DNR of appropriated monies and the administration of grants; 7) the assumption of authority to administer delegated programs under federal legislation; 8) the issuance of permits, licenses, registration, variances, or compliance schedules when such authority is delegated to the Office of the Commission; and 9) the investigation of suspected violations and the obtaining of samples.

The Environmental Control Commission, established under LEAA, is composed of seven members--The Secretaries of the Department of Natural Resources; Wildlife and Fisheries; Health and Human Resources; Commerce, Transportation and Development; Culture, Recreation and Tourism; The Commissioner of Agriculture, or their designees. The Attorney General, or his designee, serves as counsel for the Commission.

The Assistant Secretary of the Office of Environmental Affairs serves as the Commission Secretary. The five Division Administrators within the Office, for Air, Water, Hazardous Waste, Solid Waste, and Nuclear serve as technical secretaries to the Commission. The Commission's powers and duties include: 1) to adopt, amend, or repeal all rules and regulations, and standards for the protection of the environment; 2) to grant or deny permits, licenses, registrations, variances, or compliance schedules; 3) to delegate such power to grant or deny to the Assistant Secretary; 4) to issue orders or determinations; 5) to review or appeal any order of the Assistant Secretary; 6) to conduct studies or investigations; 7) to assume authority for the administration of programs under federal environmental legislation; and 8) to assume authority for the control and regulation of hazardous wastes.

In practice, the Office has been delegated responsibility for the development of the hazardous waste program, for its implementation and review and for the issuance of permits for non-commercial facilities, to adopt proposed regulatory amendments, to request that the Office conduct studies and investigations, and to issue orders and determinations.

Management of wastes in Louisiana is the responsibility of the following agencies:

Hazardous waste: Office of Environmental Affairs, Department of Natural Resources

Mining waste: Office of Conservation, Department of Natural Resources

Agriculture waste, on-site: Department of Agriculture

Infectious waste: Department of Health and Human Resources

Other solid waste: Office of Environmental Affairs, Department of Natural Resources

Mississippi: The Mississippi Solid Waste Disposal Act of 1972 grants the State authority to promulgate regulations pertaining to hazardous waste management including a regulatory program to effectively control the generation, treatment, storage, transportation and disposal of hazardous wastes. The Mississippi State Board of Health is the lead agency in implementing such a program, but several other entities are involved in carrying out specific program requirements, including Bureau of Pollution Control, Bureau of Geology, Bureau of Marine Resources, and the Department of Transportation.

The Solid Waste Disposal Act of 1974, Section 17-17-27(1)(j), provides that the rules and regulations written by the Mississippi State Board of Health which cover the management of hazardous waste must "be equivalent to the United States Environmental Protection Agency's rules and regulations." The hazardous waste regulations which have been adopted by the State track the federal regulations almost explicitly with several sections (including 261 and 265) are taken verbatim from the federal regulations. The few minor differences that do occur in the regulations are due either to circumstances unique to the State and are additions to the federal regulations that provide for a slightly more stringent degree of control by the State. State Board of Health will issue all hazardous waste incinerator permits, take all legal actions to enforce the hazardous waste regulations, and manage the manifest system wherever appropriate. The Bureau of Pollution Control will implement both the interim and final hazardous waste incinerator regulations. DSWM will acquire concurrence from Bureau of Geology on the suitability of a site from a geological standpoint and the adequacy of the monitoring system before issuing a permit.

Texas: In Texas, two agencies have designated authority for the management of solid and hazardous wastes under the Texas "Solid Waste Disposal Act." The Texas Department of Water Resources is responsible for industrial solid waste management, and the Texas Department of Health is responsible for municipal solid waste management. In accord with the State statute and the Governor's designation under Section 4006, RCRA, the departments share responsibility for hazardous waste management in the State. Neither department may subordinate its authority or responsibility to the other department. However, by mutual agreement, the Texas Department of Water Resources is the lead agency for the purpose of facilitating communication between the State and EPA.

Virginia: Although the Commonwealth of Virginia has had a solid waste program since 1971, the hazardous waste element of the program is in the developmental stages.

The 1979 session of the Virginia General Assembly enacted the "Solid and Hazardous Waste Management Act." This legislation gives the Commonwealth of Virginia the legislative base to create a comprehensive solid and hazardous waste management program totally consistent with the requirements of RCRA.

The Code of Virginia, Chapter 6, Title 32.1, Article 3 assigns the Board of Health the responsibility for carrying out the purposes of Virginia's solid and hazardous waste program and adopting compatible federal standards. The Board may also collect fees from persons operating or using facility to finance such custody and maintenance. The Division of Solid and Hazardous Waste Management is the organizational portion of the Department of Health which is responsible for the planning, development and implementation.

Oklahoma: The Oklahoma Controlled Industrial Waste Disposal Act was enacted at about the same time the Federal Resource Conservation and Recovery Act was enacted, and regulates the same elements as RCRA. These include: regulatory authority over generators, transporters, treatment, storage, and disposal facilities, manifest systems, financial security requirements, facility employee qualifications, waste lists and waste criteria with specified exceptions. The program encompasses "Controlled Industrial Waste" except for field related wastes produced by the oil and gas industry. The wastes are identical to those excluded from coverage by RCRA under 40 CFR 261.4(b)(5). In order to insure equivalency between the Federal hazardous waste universe and the Oklahoma Controlled Industrial Waste universe, the State has incorporated all of 40 CFR Part 261 by reference with certain amendments which serve to encompass a somewhat larger universe. In addition, Oklahoma has retained its existing Appendices A-1 and A-2 which are functionally similar to 40 CFR Part 251.31 and 261.32 and Appendix VIII to 40 CFR Part 261, respectively. Program is administered by the Oklahoma State Department of Health's Industrial Waste Division.

Waste Definition and Criteria: States seeking authorization must at a minimum encompass the hazardous waste universe set forth by EPA. States, with or without benefit of authorization, have and will continue to expand upon this universe. State methods for exemption or exclusion, or exception, will also vary in procedural and analytical requirements. Some States categorize waste streams, some classify sites by waste types received; some States are attempting both. The Oklahoma legislature in passing the enabling legislation, used the term controlled industrial waste rather than the term hazardous waste. For all intents and purposes, the terms have the same meaning. However, Oklahoma amended and reduced by a factor of 10 the EPA toxicity limits, so that the limits for determining if a waste is hazardous is 10x national primary drinking water standards, in comparison to 100x as set forth in the federal standards. Therefore, the universe of wastes deemed hazardous is larger in Oklahoma than that set forth nationally by EPA.

Texas facility owner or operators must develop a written waste analysis plan. This section requires an owner or operator before he treats, stores, or disposes of any hazardous waste, to obtain a detailed chemical and physical analysis of a representative sample of the waste. The plan must specify:

- the parameters for which each hazardous waste will be analyzed and the rationale for the selection of these parameters;
- the test methods which will be used to test for these parameters;
- the sampling method which will be used to obtain a representative sample;
- the frequency with which the initial analysis of the waste will be reviewed or repeated to ensure that the analysis that hazardous waste generators have agreed to supply is accurate; and,
- for off-site facilities, the waste analysis plan must also specify the procedures which will be used to inspect and, if

necessary, analyze each movement of hazardous waste received at the facility to ensure that it matches the identity of the waste designated on the manifest.

In addition, Texas Department of Health administratively determines a hazardous waste as that identified in 40 CFR Part 261, Subpart C:

- one or more kilograms in a calendar month or at any time of any commercial product or manufacturing chemical intermediate identified as acute hazardous waste and having the generic name listed in Section 261.33(e);
- one or more kilograms in a calendar month or at any time of any off-specification commercial chemical product or manufacturing chemical intermediate which, if it met specifications, would have the generic name listed in Section 261.33(e);
- 10 or more kilograms of discarded (or, intended to be discarded) containers (or any containers exceeding 20 liters capacity), in a calendar month or at any time, that have been used to hold any chemical identified as acute hazardous waste and having the generic name listed in Section 261.33(e). However, these materials are not hazardous wastes, if: a) the container or inner liner has been triple rinsed using a solvent capable of removing the commercial chemical product or manufacturing chemical intermediate; b) the container or inner liner has been cleaned by another method that has been shown in the scientific literature, or by tests conducted by the generator, to achieve equivalent removal; or c) in the case of a container, the inner liner that prevented contact of the commercial chemical product or manufacturing chemical intermediate with the container has been removed;
- One hundred or more kilograms, in a calendar month or at any time, of any residue or contaminated soil, water or other debris resulting from the cleanup of a spill, into or on any land or water, or any commercial chemical product or manufacturing chemical intermediate identified as acute hazardous waste and having the generic name listed in Section 261.33(e).

New York: has modified the definition of "discarded" to include material being burned as a fuel for energy recovery, to ensure that such wastes are included in the definition of solid waste. Moreover, New York has listed PCBs as a hazardous waste.

In Louisiana hazardous wastes are identified by criteria for definition and by classification:

- Category I: Those known chemicals and process streams whose hazardous nature have been prescribed by prior determination and which are presented in either of the two lists of Appendix A of the State regulations.

- o Category II: Those special waste categories defined in Section 4.2.1E, generally consisting of large volumes with consistent characteristics such as typical mining wastes.
- o Category III: Other wastes possessing any of the characteristics of the hazard classes listed in Appendix A of the State Regulations and carrying a hazard rating of 2 or higher as specified. Hazard classes of concern are ignitability, corrosivity reactivity and toxicity.

In addition, a special waste category is established which includes two specific waste streams--red mud and gypsum residue, and one generic class--wastewaters in the NPDES treatment trains.

Waste Exclusions/Exceptions

In some cases, the difficulty lies in determining whether or not a waste is excluded, exempted, excepted, from the hazardous waste program. In Texas, a hazardous waste which exhibits characteristics established in 40 CFR Part 261, Subpart C but not specifically identified and listed in Subpart D is not subject to the regulations, if:

- o the waste is beneficially used or reused or legitimately recycled or reclaimed
- o the waste is accumulated, stored, or physically, chemically or biologically treated prior to the beneficial use or reuse or legitimate recycling or reclamation.

Such wastes meeting the characteristics detailed in Subpart C and listed in Subpart D are excepted but not exempted if the waste is transported or stored prior to being used, recycled, or reclaimed.

Flyash, bottom ash, slag, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels are non-hazardous. Municipal hazardous waste generators are not subject to the requirements for identification, and notification, but generators must ensure the wastes is properly handled on site or disposed of in an authorized off-site facility.

The issue at hand is development of a regulatory stance which encompasses the universe of hazardous wastes while at the same time encourages rather than stifles recovery of materials in regulated waste streams. Consequently, the regulated community will face the dilemma of deciding whether or not a waste is encompassed or not, and if so what portions of the record keeping, manifesting, and permitting requirements are applicable.

Financial Requirement, Penalties, Licenses

While RCRA does not impose permit or licensing requirements on hazardous waste transporters, many States either license or certify hazardous waste transporters. In Pennsylvania no person or municipality may transport hazardous wastes within the State without a departmental license. Moreover, transporters must file adequate bonds with the Department of Natural Resources.

While many States enacted legislative amendments to increase penalty schedules up to the federal level in order to evidence equivalency with RCRA files, Pennsylvania's are more stringent:

- summary offense--$100 minimum fine, $1,000 maximum, or a maximum of 30 days imprisonment
- misdemeanor, third degree--$1,000 minimum fine, $25,000 maximum, and/or maximum of year imprisonment.
- misdemeanor, second degree--$2,500 minimum fine, $50,000 maximum, and/or a maximum of two years imprisonment.
- felony, second degree--$2,500 minimum fine, $100,000 maximum, and/or between two and ten years imprisonment.
- felony, first degree--$10,000 minimum fine, $500,000 maximum, and/or between two and twenty years imprisonment.

While RCRA does not prohibit transport licenses and more stringent penalties, neither does the federal statute preempt the States from enacting "perpetual care" funds in addition to the financial requirements set forth in federal regulations. The issues of "perpetual care" funds application and compensatory legislation at the State and federal levels face the entire regulated community.

State Measurement Needs: State administrative entities have identified a plethora of technical assistance needs in hazardous waste management which range from personnel training to satellite mapping. One major need that deserves attention in relation to its potential short and long term economic and legal ramifications, is the States' ability to sample, test, measure and analyze hazardous wastes.

In 1980 the Office of Recycled Materials, National Bureau of Standards sponsored a study by the Association of State Territorial Solid Waste Management Officials (ASTSWMO) to determine State measurement needs for both Subtitle D; solid waste management, as well as Subtitle C; hazardous waste management. The results of this study are accurately and sufficiently expressed in ASTSWMO congressional testimony: "Laboratory measurement needs for waste characterization and monitoring of facilities is a critical unmet need, without which formulation of a standard RCRA quality assurance program cannot be achieved."

EPA requires that within 60 days of the effective date of the memorandum of agreement between the EPA Regional Office and the State for authorization of the State program, a review be conducted to define the existing capability of the designated laboratory to conduct the hazardous waste analytical program.

Of the States surveyed by the Association in its study (Texas, Virginia, Mississippi, New York, Pennsylvania, Oklahoma, and Louisiana) each employs a different organizational and procedural method to conduct the analytical programs.

Louisiana: currently uses a commercial laboratory, although a joint laboratory with other divisions of the Office of Environmental Affairs, Department of Natural Resources, is planned. A contract laboratory will be used for the immediate future. Since the DNR is dependent upon contract laboratories for sampling and analysis, the department has developed an Analytical Operations Procedures Manual. Standard test methods and equivalents are referenced and special test protocols outlined. Any laboratory which desires to be considered for use must employ established EPA test procedures or other recognized methodology where EPA has not set procedures. Certification will be required where such a system exists and must comply with applicable federal, State, and local regulations. Annual audits will be conducted. This evaluation will include processing of spikes and blanks as developed by EPA.

Oklahoma: utilizes the services of the Water Quality Laboratory within the Department of Health for its sampling needs. The laboratory while well equipped with state-of-the-art instrumentation, has personnel who are not familiar with scope of the RCRA hazardous waste program, its measurement needs, or the laboratory needs of the Industrial Waste Division. Communication with field personnel is minimal, however, the laboratory has initiated a quality control program which includes duplicate and spike analysis, control charts and monthly reports to verify that the quality control program is being maintained. To date only a few samples have been required for analysis.

Pennsylvania: utilizes the services of the Bureau of Environmental Laboratories. The laboratory has been handling solid waste samples. Problems have occurred in communication with field personnel, particularly conveyance of the handling of the sample and subsequent determination and evaluation of analytical results. The laboratory does not have a manual but has prepared a short description providing necessary chemical analysis, standard methods of analysis, and evaluation techniques for state-specified parameters.

The Virginia Division of Consolidated Laboratories performs all laboratory work for the State. The laboratory is divided into sections: 1) Forensics; 2) Bureau of Microbiological Sciences; 3) Bureau of Product Regulation; and 4) Bureau of Environmental Sciences which conducts sampling in water, air, drinking water, radiation health, blood lead levels, and solid and hazardous wastes. Quality assurance is emphasized. The Board of Health and the Chesapeake Bay Commission want to donate funds for new equipment for the laboratory, but cannot do so until more space is available. The laboratory is currently handling approximately 100 samples per year of hazardous waste.

Mississippi laboratory support will be available as needed with laboratory arrangement made prior to sampling, except in cases of spills or emergencies. Sampling and sample transport is the duty of the Division of Solid Waste Management personnel; laboratory personnel will have responsibility for non-field analytical testing only. The Bureau of Pollution Control Laboratory will provide analytical services for ground water and surface water samples. Additional services (e.g., organic scans, tests for ignitability, reactivity) are provided on a contractual basis by another lab or by a private laboratory.

In New York waste analysis requirements are set forth according to the facility type: tanks, surface impoundments, waste piles, secure land burial facilities, land treatment/food chain crops, unsaturated zone monitoring, closure and postclosure, incinerator, energy recovery facility, thermal facility and chemical, physical, biological treatment processes. The Department of Health must approve of ancillary laboratories.

The Texas Department of Health Laboratory requires additional facilities, test equipment, staff, and safety devices. The laboratory has, however, an interim EPA certification to perform analyses of samples under the Safe Drinking Water Act. The laboratory also conducts approved analyses of wastewater treatment effluent for the Texas Department of Water Resources in its program under the Clean Water Act. In FY 1981 the department requested $72,000 for laboratory support in order to meet the EPA protocol for quality assurance. The request included $33,000 for equipment for improved capability for organic and inorganic monitoring.

In recent public meetings on the final land disposal regulations, EPA representatives have reminded the regulated community that the testing methods cited in Appendix VIII are guidelines, and recommend test methods in certain areas are absent. States can require or accept differing testing and analytical techniques to be conducted in varying institutional frameworks. Given the measurement needs cited by the quality assurance at the State level, comparability among the States cannot be assumed.

The impact on the regulated community is obvious--in the short term, the inclusion/exclusion of a waste stream in a regulatory program may require substantial, expensive testing; and, in the long term, identifying and analyzing waste samples from closed or abandoned facilities may result in financial burdens either misplaced or overplaced on specific generators.

Federal, State Priorities. EPA stated the federal priorities in a memorandum from headquarters to the regions and States: "We expect to be able to begin calling Part B permit applications for existing incinerators in the fourth quarter of FY 1982. However, there is a six month lag in the effective data for both the standards for land disposal facilities and the supplemental standards for surface impoundments. Therefore, we will not be able to call in Part B for these facilities until the second quarter of FY 1983." In FY 1983, the regions and States are likely to concentrate their activities in the following areas:

- State authorization
- Interim status compliance and enforcement
- Permitting

While permit activities will be receiving a much higher level of attention in FY 1983 than before, there will still be many years before all hazardous waste facilities receive RCRA permits. In the interim the regions and States should conduct an adequate number of inspections to ensure that facilities are complying with the interim status standards or the authorized State analogue. Compliance inspections for groundwater monitoring and land disposal facilities are likely to be the most important. Every land disposal facility is to be inspected during FY 1983 to determine compliance with the groundwater monitoring requirements.

In summary, specific high priority activities are expected to be:

- program development for interim and final authorization
- compliance inspections and enforcement of groundwater monitoring at all land disposal facilities
- issuing permits to incinerators
- completing action on storage and treatment permits called in during FY 1983
- calling in Part B and beginning the permit issuance process for land disposal facilities.

In addition, States can develop implementation schedules which will ensure siting of the necessary hazardous waste management facilities within State borders. State plans can also encourage waste exchanges and other waste utilization practices.

Many States have already begun development or support of such activities (Texas, Virginia). However, the permit applicant for a new facility would be wise to ascertain the particular State's priority before embarking on an expensive site survey an preparation program.

Degree of Hazard: Many States have approached the problem of differentiating waste streams according to volume, impact on public health an the environment, acceptability of land versus treatment management. In congressional statements, the States have supported a national approach to this concept and described a proposed work scope submitted to EPA:

- evaluation of current State laws and regulations to determine consistency among States and substantive deficiencies in terms of promulgated or proposed regulations under Subtitle C.
- analysis of State insurance requirements
- collection and evaluation of existing data on hazard criteria
- recommendations of a technically feasible and cost effective implementation procedure for achieving a nationally uniform State managed RCRA Subtitle C program for protecting human health and the environment.
- assessment of State institutional barriers to the implementation of the proposed procedure.
- identification and prioritization of needs required of the selected implementation procedure.

While EPA has declined to fund this coordinating activity, many of these activities are already underway in the States and in the private sector. The consistency of data collection and evaluation, and the availability to all interested parties remain open for review and discussion.[1]

Siting. Many States, such as Pennsylvania, currently do not have any waste treatment, storage, disposal facilities permitted within their borders. Other States such as New York have limited land disposal and treatment capacity but no incineration capacity within their borders. To address and alleviate this limitation, State legislatures have enacted siting statutes. Two examples illustrating different approaches to the problem are the New Jersey Hazardous Waste Facility Siting Act (S1300) and the Massachusetts Hazardous Waste Facility Siting Act (Chapter 21D).

The New Jersey Hazardous Waste Facility Siting Act established a Commission comprised of three industry members, three local officials, and three environmentalists. The Commission is charged to propose sites for new facilities based upon facility siting criteria established by the New Jersey Department of Environmental

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[1] Nevertheless, States could use proposed degree-of-hazard schemes to set disposal fees on a per ton basis. For example, if the W-E-T scheme (see Appendix VII) were chosen, fees could be set on some basis such as that illustrated in Fig. AX(1). In this instance, per ton fees have been made to depend on W-E-T score and potential population, N, who might be exposed. (Note added by H. Yakowitz)

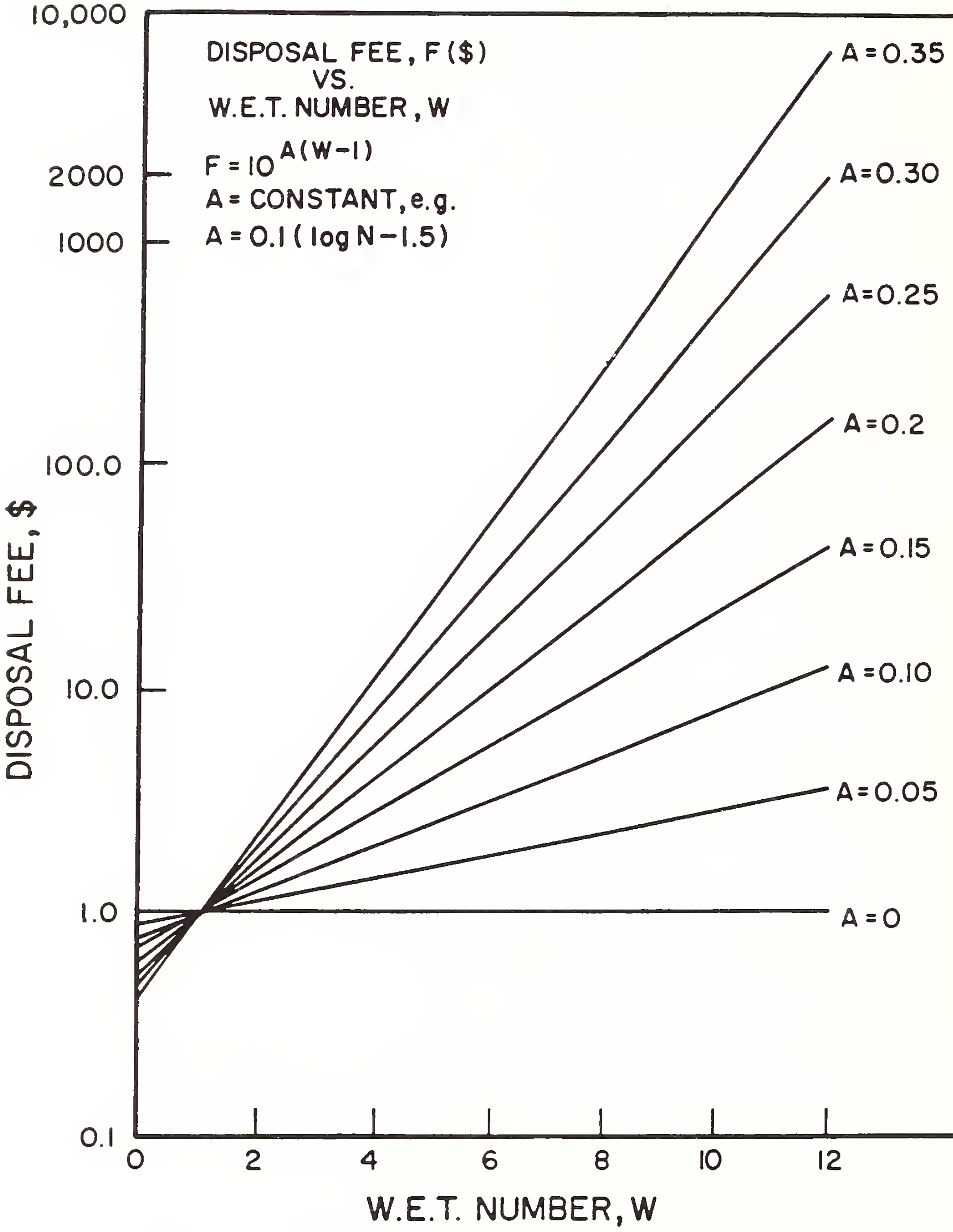

Figure X.1. Possible per ton disposal fees, F, vs. W-E-T number (N is number of persons who might be exposed).

Protection. The Commission may designate alternate or additional sites for new major hazardous wastes facilities at the request of the hazardous waste industry; the requestor will have the burden of proof concerning the suitability of the site in proceedings. If the DEP license is granted, the owner/operator may construct and operate the facility without regard to any local requirements or ordinances.

The Massachusetts Hazardous Waste Facility Siting Act is different than the New Jersey concept in that this law is predicated on the belief that the facility siting matters are best addressed through negotiations between developers and the host communities. Those negotiations are to be conducted on a case by case basis. Host communities are represented by local assessment committees in the negotiations process.

The State Site Safety Council is composed of eight State commissioners, six representatives of State professional organizations, and seven members of the public. The Council addresses the social and economic impact of proposed facility projects and awards technical assistance grants to local assessment committees in order that they may evaluate proposed facility projects and determine the compensation to be paid by a facility developer. The compensation must address the adverse impacts to communities abutting that in which the facility is to be sited. A siting agreement is reached through compromise and any impasse is resolved through binding arbitration. The statute also provides that no local license or permits for the facility are to be required of a developer which were not required on or before the effective date of the act.

The expectation that States will be reviewing the possibility of locating such facilities on or near federal lands is reasonable and discussions are underway in some western States. Community acceptance and the site specific aspects of postclosure engineering and financial responsibility remain at issue.

Summary and Outlook

Despite funding shortages and dilemmas, States will continue to assume, administer, and expand their respective hazardous wastes programs. Funding will be supported through a combination of fees and appropriations. By 1984, the majority of States are likely to have authorized hazardous waste programs in place. Concurrently, as a result of federal funding and staff reductions and completion of State assumption process, the direct involvement of federal regulatory agency can be anticipated to lessen. Implementation issues (e.g., State-to-State consistency) will come to the fore. Resolution at the regional level will be attempted. Technical difficulties will arise should States measurements needs not be addressed. Debate on perpetual care and victim compensation will be aired in Congressional and State legislative debates as part of the regulated community need to be apprised of the legislative, technical and economic issues.

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APPENDIX XI. DEVELOPMENT AND USE OF A SIMULATION MODEL FOR THE ECONOMIC ANALYSIS OF RESOURCE RECOVERY OPTIONS

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FOREWORD

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The Secretary of Commerce under Subtitle E, Resource Conservation and Recovery Act of 1976 (P.L. 94-580) is charged to provide a forum for the exchange of technical and economic data relating to resource recovery facilities. The Office of Recycled Materials in support of this mandate identified a major economic issue faced by communities in selecting resource recovery systems: the provision of the maximum energy output for the least cost versus the reuse of materials in the municipal waste stream. This issue, often described as the "burn v. recycle" dilemma, has entailed the enactment of local waste flow control ordinances, protests from public and private sector recycling organizations, notably companies engaged in post-consumer newsprint recovery, as well as potential facility operators and the financial community. The Office of Recycled Materials commissioned this report, prepared by the Bureau of Industrial Economics, U.S. Department of Commerce, to provide interested parties with an economic assessment tool necessary to evaluate the financial aspects of each option on a case-by-case basis. Consequently, this report does not attempt to provide a definitive answer to the "burn v. recycle" issue but to provide a method to consider economic tradeoffs in selecting a particular waste management option. A community's decision in reviewing resource recovery options is predicated on the specific financial, legal, institutional, and political aspects which can only be quantified or addressed by affected parties at a particular point in time.

Recognition is well-deserved for the efforts of the following individuals who prepared and assisted in the preparation of this report:

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A SIMULATION MODEL FOR THE DEVELOPMENT AND USE OF AN ECONOMIC ANALYSIS OF RESOURCE RECOVERY OPTIONS

Abstract

A simulation model was developed and used in differing scenarios in order to conduct an economic analysis and comparison of resource recovery options. Five solid waste disposal strategies with specific parameters were compared economically. Under conditions specified in case studies, resource recovery facilities were found less economically desirable than landfilling. Concurrent factors which would tend to make resource recovery an economically preferable alternative are 1) steam prices over $4.00 per 1,000 lbs in 1980 prices; 2) landfill costs over $18 per ton; 3) resource recovery facility construction costs less than $28,000 per ton/day of capacity; and 4) operating and maintenance costs below $9 per ton of garbage. Operating rates above 90 percent of intended throughput are necessary for efficient operation; thus experimental or overambitious designs should be approached with caution.

Source-separated waste newspapers are usually more valuable as fiber to make recycled newspaper than as fuel. However, when steam is valued at more than $4 per thousand pounds, source-separated waste newspapers may be more valuable as fuel.

The reader is cautioned, that 1) any simulation model may not exactly reflect conditions in one's own community; and 2) should be employed as one of many methods available to the decisionmaker. Lastly, a model is a tool in the decisionmaking process and not a rigid determinant of any one particular solution.

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Purpose of the Study

This economic simulation model was developed with dual objectives:

1) To help the National Bureau of Standards Office of Recycled Materials simulate the economics of proposed Resource Recovery Facilities (RRF's) in order to analyze the economic merits of each scenario.

2) To determine the economic trade-offs involved in selling waste newspapers to paper recyclers instead of burning the paper in resource recovery facilities to generate energy. The analysis of trade-offs is done chiefly from the point of view of the municipal planner.

Background

Until recently garbage has generally been considered a nuisance rather than a resource. In passing the Resource Conservation and Recovery Act (RCRA) of 1976 (P.L. 94-580), Congress recognized the potential value of materials and energy in the garbage, as well as the environmental benefits of reducing the need for disposal.

Approximately 60 recovery facilities have been completed or are under construction[1]. Some of them are designed to recover scrap metals and glass, and all of them are designed to recover energy from the combustible components of garbage. The economics of resource recovery are such that the potential energy revenue is much greater than the potential revenue from recovered scrap metals and glass. Thus, the make-or-break operation in a recovery facility is the energy recovery operation.

There are several basic methods for recovering energy from garbage, the most common of which are:

1) Mechanically producing a refuse-derived fuel (RDF) for sale as a boiler fuel.

2) Burning garbage to produce steam, which is then sold to an industrial facility or used for district heating and cooling.

3) Burning garbage to produce steam which is used to generate electricity, for sale to an electric utility.

4) Burning garbage along with sewage sludge in order to jointly dispose of both wastes.

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[1] National Center for Resource Recovery, Washington, D.C.; NCRR Bulletin, September 1980.

5) Capturing landfill gases from mature disposal sites.

While difficulties in producing a marketable fuel have been encountered, facilities employing the first method have provided RDF. The third and fourth methods are more complex and are not at present widely used. The fifth method, methane from landfills, is not an alternative to landfilling. The second method, burning garbage to raise steam, is the most common type of RRF and is the focus of this study.

Until recently, economies of scale in recovery facilities was a commonly held belief. A survey of existing RRF's which produce steam challenges this belief. The costs for fourteen facilities with production capacity ranging between 50 and 1200 tons per day indicate that the capital cost per ton of capacity does not decrease with size, and may even increase. (See table 1 and figure 1.) Study further reveals no obvious economies of scale in operating and maintenance costs per ton of throughput. (See table 2.)

These conclusions regarding economies of scale require further assessment. Even though the plants listed in tables 1 and 2 were planned to be or are operating, steam-producing RRF's, there is still wide variation among them. For example, some attempt to recover scrap metals from the garbage while others did not. Some have back-up boilers. Some were built with longer facility life. Furthermore, to a great extent, the high operating costs per ton of garbage input experienced by large RRF's result from low capacity utilization rates. With increasing experience, large RRF's may be able to operate at rates closer to full capacity, thus spreading costs over more input tons.

Although the apparent lack of economies of scale may not be good news to planners in Standard Metropolitan Statistical Areas (SMSA's), medium-sized towns may be attracted to resource recovery. Assuming the citizens of a municipality generate 4.2 pounds of garbage per capita per day (national average), a town with a population of 25,000 produces enough garbage for a fifty ton per day recovery facility. There are approximately a thousand towns in the United States with 5,000 or more inhabitants, which could individually or jointly sponsor a recovery facility of this size.

Paper and other post-consumer wastes have been recycled for decades. Recycled newsprint has historically been obtained from "source separated" waste newspapers. Newspapers account for about 7 percent of municipal solid waste. In 1980 only about one fourth of this 7 percent was source separated and recycled[2]. Twenty-five percent of the newsprint produced in the U.S. in 1980 was

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[2] Bureau of Industrial Economics, U.S. Department of Commerce; Marketing Information Report: 1980, Waste Newspapers in Four South Atlantic States, 1982.

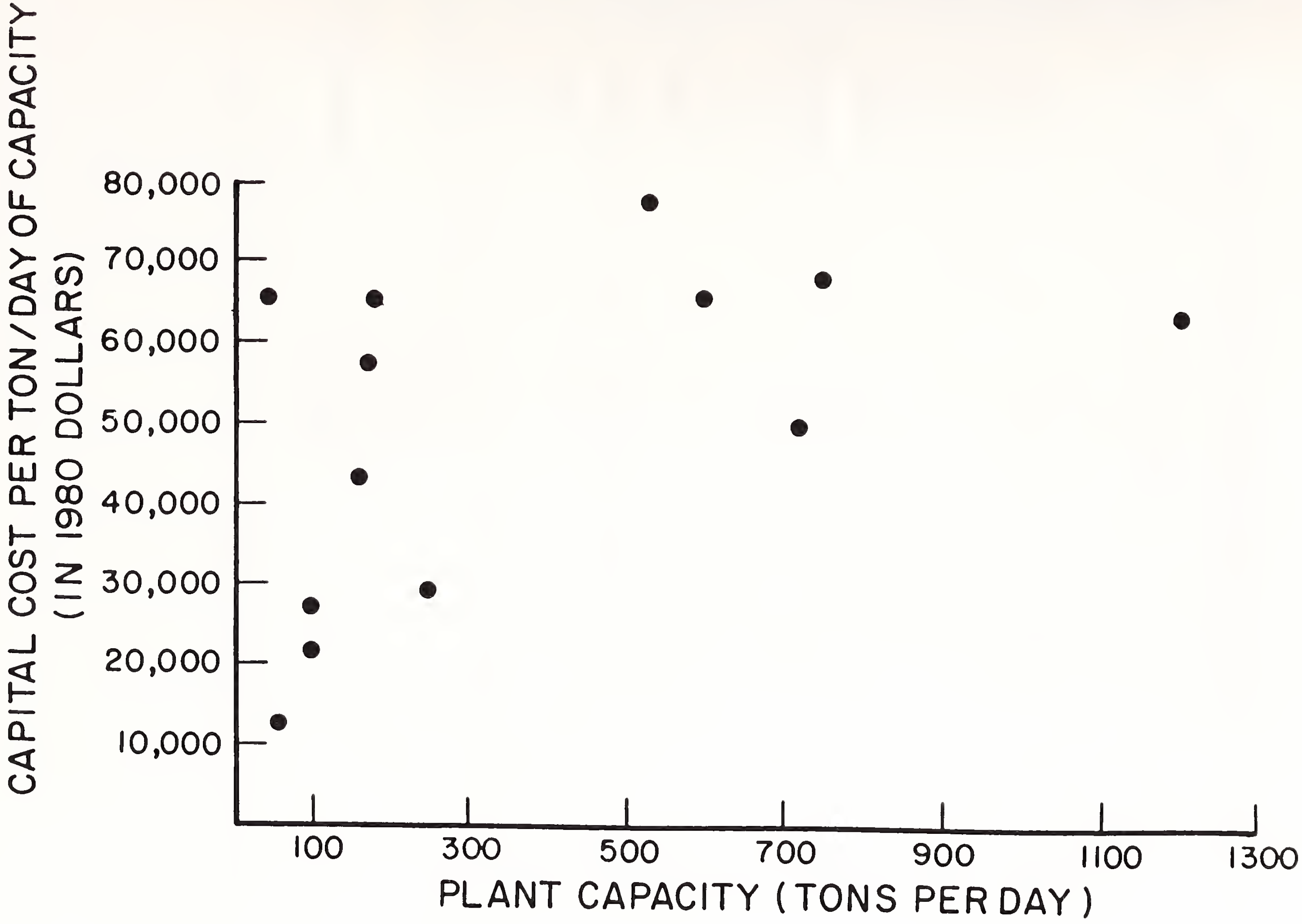

Figure 1. Economies of Scale in RRF Size.

Table 1. Construction Costs for RRF's Producing Steam Only

	Capacity tpd	Capacity Cost /ton
Salem, VA (modular)	100	$27,000
Osceola, Ark (modular)	50	65,000
North Little Rock, Ark (modular)	100	22,000
Crossville, TN	60	13,300
Waukesha, WA	175	58,000
Saugus, MA	1200	64,000
Portsmouth, VA	160	43,000
Oceanside, VA	750	68,000
Norfolk, VA	180	65,000
Nashville, TN	530	78,000
Harrisburg, PA	720	49,700
Braintree, MA	250	29,600
Baltimore City, MD	600	65,300
Average	375 tpd	$49,800 /ton
Total	4875	-----
Range	50-1200	$13,300-$78,000

Note: Construction costs were inflated to approximate 1980 dollars, using the Department of Commerce Composite Construction Cost Index.

Table 2. Operation and Maintenance Cost per ton of Garbage Processed
RRF's Producing Steam Only

	Capacity (tpd)	Gross O & M Cost per ton burned ($/ton)
Salem, VA	100	$17.12
N. Little Rock, AR	100	12.00
Norfolk, VA	180	29.63
Nashville, TN	530	17.70
Harrisburg, PA	720	14.25
Baltimore City	600	14.00[e]
Average	372 tpd	$17.5/ton

e = estimated for 1980. 1979 cost was $12.87/ton

Note: Operation and Maintenance costs for following facilities were not available:
- Osceola
- Crossville
- Waukesha
- Portsmouth
- Oceanside
- Braintree
- Saugus

manufactured using source separated newspapers[3]. The key feature of source separation is that the consumer separates the newspapers from other trash, which are collected separately, either by private groups or municipal collection services. Source-separated newspapers are unlikely to constitute more than two to four percent of the total garbage flow for most municipalities.

Newspapers are one of the most valuable constituents of garbage, in terms of both fiber value and energy content. Unfortunately, paper recycling and energy recovery are mutually exclusive uses for wastepaper. As uses for wastepaper expand, competition for waste newspapers will increase.

Allocation of the finite supply of waste newspapers among competing uses may not always be resolved by market forces. In order to ensure adequate input to energy producing recovery facilities, some local government sponsors have passed "flow control" ordinances. These ordinances usually limit the extent to which private sources can collect source-separated newspapers, and often require that all postconsumer waste be directed to the recovery facility for processing.

The value of paper as a fuel varies not only according to time and location, but also according to the fuel it is being substituted for. For example, if market price of waste newspaper is $66 per ton,[4] newspapers are much more expensive per million Btu than is coal at $25/ton, but newspaper is considerably cheaper than No. 2 fuel oil at $42/barrel. (See table 3.) Thus, if paper displaces fuel oil, or if the steam from a RRF is being sold to a customer willing to pay a high price for a guaranteed supply of energy, paper can be an economical fuel.

Description of the Model

The model simulates a recovery facility which produces steam for sale to an individual customer for heating, cooling, or industrial purposes. The simulation model estimates the financial viability of specific configurations of resource recovery facilities. The model also examines the trade-offs involved in selling waste newspaper for recycling vs. burning in a recovery facility.

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[3] This estimate was deduced by Howard Post, paper industry analyst for the Bureau of Industrial Economics, from the American Paper Institute Publication Paper, Paperboard, and Woodpulp Capacity and Fiber Consumption, 1980.

[4] Bureau of Industrial Economics, U.S. Department of Commerce; Marketing Information Report: 1980, Waste Newspapers in Four South Atlantic States, 1982. This was the average waste newspaper price in four Southeastern States in 1980.

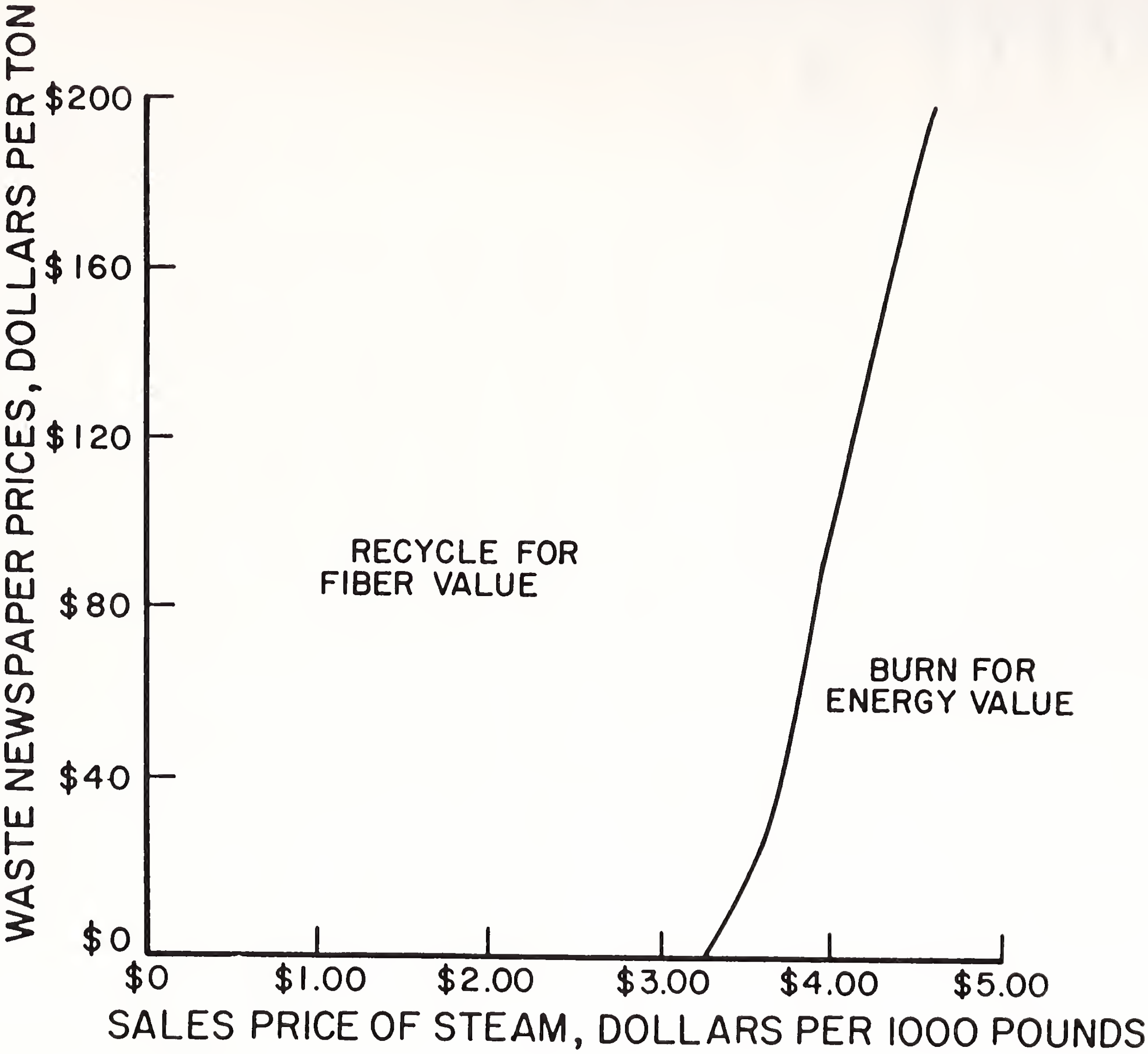

Figure 2. Trade-Off Prices for Waste Newspaper.

Table 3. Energy Prices per Unit, for Newspapers and Selected Fossil Fuels

Commodity	Price*	Energy Content	Energy Price
Dry Newspapers	$66/ton	14mmBtu/ton	$4.71/mmBtu
Bituminous Coal	$25/ton	26.2mmBtu/ton	$0.96/mmBtu
No. 2 Fuel Oil	$42/bbl	5.8mmBtu/bbl	$7.24/mmBtu
Residual Fuel Oil	$31/bbl	6.3mmBtu/bbl	$4.92/mmBtu
Interstate Natural Gas	$2.10/mcf	1.03mmBtu/mcf	$2.04/mmBtu

Note: Prices may vary widely by location and over time. Prices reflect market charges and do not address the material handling, burning characteristics or environmental impacts of different fuels.

While non-financial considerations often are pivotal in the decision whether or not to build a RRF, this analysis deals almost exclusively with financial considerations. The environmental benefits of a RRF may be worth the extra cost to a community in order to mitigate landfill requirements.

A significant consideration for municipal planners is that resource recovery facilities are not a total replacement for land disposal. After garbage has been burned in a RRF, ash and other unburnt waste remains. A rule of thumb is that the unburnt residue is equal in volume to about 20 percent of the input garbage. This residue must be disposed or utilized in some fashion (e.g., road patch).

An option examined in the model is landfilling. This non-recovery option for garbage is the most prevalent form of disposal in the United States. It is the only alternative for the non-recyclable portion of the garbage.

The model produces estimates of the net benefits from five alternative waste management options. These five strategies consist of combinations of 1) landfilling, 2) energy recovery, and 3) resource recovery. The five alternative options are:

1) Landfilling all garbage, no source separation of newspapers.

2) Source separating newspapers, landfilling the remaining garbage.

3) Source separating newspapers, and burning the remaining garbage in a RRF with no back-up fuel.

4) Burning all garbage in a RRF with no back-up fuel, no source separation of newspapers.

5) Burning all garbage in a RRF using source-separated newspapers as back-up fuel.

The first option, landfilling, is self-explanatory. Landfilling will always yield negative financial benefits (i.e., costs), but landfill may nevertheless be the least-cost method of disposal if the other options are money-losing propositions.

The second option requires source-separating newspapers so that the newspapers meet market specifications. This paper is then sold and the remaining garbage landfilled.

The third option requires source separating newspapers and burning the residue in an RRF; thereby producing steam for sale. There is no attempt to recover waste materials such as glass, aluminum, or ferrous metals. Burning garbage reduces landfill costs, and this saving is added to the net revenue from sale of steam and sale of newspapers.

The fourth option assumes that all garbage, including newspapers, is burned in the RRF without source separation. Again, burning garbage reduces landfill costs and this saving is added to steam sale revenues.

The fifth option is an important variation of the fourth. In this case source-separated newspapers are used as a back-up fuel to improve the combustion of garbage. Slugs of wet garbage or other low combustibles can hamper burning thereby creating a serious operating problem for steam-producing RRF's. Some facilities use backup fuels such as natural gas or #2 fuel oil to improve combustion and to help in start-up[5]. This practice nullifies much of the energy-conserving rationale for resource recovery, and this practice will become increasingly more expensive if energy prices rise. Source-separated newspaper has a high energy value if kept dry until needed. Dry paper burns cleanly, has an energy content of about 14 million Btu/ton. The model allows for a higher operating rate for this option as compared to a facility that does not use back-up fuel, such as options three and four.

The model utilizes twenty-nine (29) input variables. If the first three variables--capacity, constructed cost, and ton/day--are not known, the program will estimate them. This is done by assuming that the construction cost for a given facility will be the same on a per capita basis as that specified as the national average. These 29 input variables are defined in table 4.

The model is dynamic, calculating costs over the 20-year life of the options with changing prices. There is an economy-wide rate of inflation forecast for the period, with differential rates of increase optional for energy prices, paper prices, and landfill costs. The model utilizes the concept of present value, in which benefits from future years are discounted by a rate of return to make future dollars comparable to present dollars.

The "bottom line" in the model is the average annual present value of each of the five options. The option that has the largest average annual discounted value over the twenty-year period is the most economic. In most of the economic simulations all five options have a negative present value. This is not surprising, since disposal of garbage has always been a cost to society.

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[5] U.S. Conference of Mayors, Akron: A Case Study of Economic Development and Resource Recovery, March 1980.

U.S. Conference of Mayors, Nashville: A Case Study of Economic Development and Resource Recovery, March 1980.

U.S. Conference of Mayors, Saugus: A Case Study of Economic Development and Resource Recovery, March 1980.

The model arbitrarily assumes that the RRF will experience a 20-year life, and is financed with 20-year bonds. In reality the useful life of these facilities is impossible to predict with certainty. Although the structures will probably last more than 20 years, the facility may become obsolete long before the end of its physical life.

Although this simulation model contains no explicit consideration of subsidies for energy producing facilities, the effects of many types of subsidies may be evaluated with this model via comparative analysis. That is, a simulation is run for a specific case without subsidy(ies) and then compared to a simulation where a subsidy's effect on a variable is incorporated. Examples would include: 1) a full faith and credit guarantee by the federal government of the bonds used to finance the RRF might reduce the interest rate from 12 percent to 9 percent; and/or 2) federal government price guarantees that could increase the sales price of steam by $1.00 (or more) per thousand pounds.

Description of Input Variables

PPrice = Sales Price of Newsprint per ton Most paper dealers will consider long-term contracts to purchase waste newsprint from a municipality. Unless a long-term contract can be obtained, the sales price could fluctuate wildly and no market might exist during recessions. A long-term contract should include a provision indexing the sales price to some measure of inflation.

SPrice = Sales Price of Steam (per thousand pounds) Since every steam-supply situation is unique, the sales contract will be custom-designed to the situation. The sales price of steam is often based on the cost of alternate fuel. For example, the price per 1,000 pounds of steam may be stated as 0.15 times the price of a ton of coal. This type of formula contains a built-in cost escalator, which is essential in any long-term contract.

The decision model does not deal directly with subsidies for recovery facilities, because it is not certain what kinds of subsidies, if any, will be available. However, through judicious use of the model, most types of subsidies can be simulated.

It is usually assumed that energy prices will increase somewhat faster than the general rate of inflation. The model allows for a special energy inflation rate if the planner thinks this would be appropriate.

LFLCOS = Landfill costs per ton of garbage dumped These costs would include the annualized expenses of purchasing and improving the site, as well as the operation and maintenance of the facility. For those instances where municipal landfills generate revenues greater than all expenses, this model would understate the attractiveness of the landfill option. Conversely, where landfills operate at a loss or where land costs are amortized at less than replacement costs, this model would overvalue the landfill option.

As far as this economic simulation is concerned, landfilling and ocean dumping are the same option.

Although it is usually assumed that landfill costs will increase at the same rate as overall inflation, the model allows planners to assume a different rate for landfills. For example, if a landfill site suitable for 20 years can be purchased for a fixed principal and interest cost, then landfill costs should increase more slowly than average. On the other hand, where landfill capacity is limited and land costs are increasing faster than overall inflation, it would be appropriate to use a higher escalator factor.

TRMill = Transportation to Paper Mill (per ton of paper) A BIE survey found that transportation costs averaged 14 percent of the mill-delivered price of waste newspapers. Costs ranged from $5 to $17.50 per ton, and averaged $8.45 per ton. Paper sales contracts may or may not include transportation costs. If the paper customer pays the freight, this item would be zero. Otherwise the paper mill purchases waste newsprint at it unloading platform, with the seller bearing the cost of transportation and handling. The model assumes that transportation costs will rise at the same rate as overall increases. (Although transportation consumes greater quantities of energy, energy costs are usually about 15-20 percent of trucking costs.) Although transportation costs vary widely, a preliminary estimate can be obtained as follows:

Cost per ton = 20¢ x (Distance to paper mill + return trip). This formula gives 1980 costs. Distances are expressed in miles. If rail transport is available, the cost could be much less.

TRLFL, TRENR, TRXX = Transportation to Landfill, Transportation to RRF, and Transportation from RRF to Landfill These are the per-ton costs of transporting garbage from the end of the collection run to the disposal facility, plus the return trip. If there is a central collection point where garbage is sent by truck or rail to the disposal facility, transportation costs would begin at this point.

A rough estimate of the total transportation costs per ton-mile is $0.20 in dollars including the mileage for the return trip. The model assumes that transportation costs will rise at the same rate as overall costs.

CSEP = Extra Cost of Source-Separating Waste Newsprint (per ton) Unless waste newsprint is source-separated, it will become too contaminated to be recycled. In most municipalities where waste newsprint is source-separated there is no measurable cost, since the public does this as part of the waste disposal process. It might be argued that there should be come cost allowance for public inconvenience or for the cost of policing a source-separation ordinance. Otherwise this cost factor should be zero.

CCOL = Extra Cost of Collecting Source-Separated Garbage (per ton) Because of special handling and storage requirements, it is normally more expensive to collect source-separated newsprint. Waste newsprint would have to be collected in a separate truck or stored in a separate section of the collection truck. It would normally have to be transported to an assembly area where it might have to be stored before it could be shipped to the paper mill.

CONCOSTA = Total Constructed Cost of RRF This cost factor includes the entire capital outlay - land, plant, equipment, access roads, auxiliary facilities - needed to construct and operational facility. Because this cost varies with size, location, and vendor this value should be obtained from an engineer's evaluation.

An analysis of thirteen operating steam RRF's found that the constructed cost of garbage-burning capacity ranged from $13,300 per ton-day to $128,000 per ton-day, with an average cost of $54,800 per ton-day (all costs converted to 1980 dollars). The facilities ranged in size from 50 tons per day to 720 tons, with no significant trend in economies of scale.

INTRATE = Interest Rate on Municipal Bonds The rate used should be the rate that would be incurred on a new issue of long-term general obligation bonds. Although it once was standard practice to use the average rate on outstanding bonds, this is no longer appropriate because current marginal rates are much higher than current average rates. This value should be entered as a decimal.

DISRATE = Discount Rate for Present Value of Future Dollars Present value is a financial concept which deals with the fact that a dollar receivable at some future date is less valuable than a dollar owned at present. (In layman's terms, a bird in the hand is worth more than one in the bush). The value of future dollars is discounted at a rate which makes them comparable to dollars in hand. In theory, determining the discount rate is a complicated exercise in evaluating future inflation rates, risk analysis, and alternate uses of funds. In practice it may be acceptable to use the municipal bond interest rate as the discount rate for a preliminary analysis. A more advanced analysis should consider using a discount rate somewhat higher than the interest rate, in recognition of the risks that would be incurred. The value should be entered as a decimal.

OPMAINA = Annual Operation and Maintenance Costs for the RRF per ton O&M costs can best be determined by an engineering analysis, since these costs can vary widely with plant size, location, and facility design. It is noteworthy that most existing RRF's have experienced cost over-runs. An analysis of nine operating steam RRF's shows that O&M costs per ton of garbage burned averaged $17.45 per ton in 1980, with no significant trend in economies of scale.

Annual Sales of Steam (in thousands of pounds) This value is determined internally by the decision model. It is the product of the Btu value of the fuel per ton, the number of thousands of pounds of steam per million Btu's, the designed burning efficiency, tons per year of newspaper burning capacity, and the capacity utilization rate.

RINF, INCEN, INCPAP, INCLFL = Forecasted Inflation Rates The effects of inflation will distort a long-range investment decision, especially since various cost factors will be increasing at different rates. For example, this model allows the planner to assume that the value of energy will grow at a faster or slower rate (INCEN) than the average inflation rate (RINF). This capability also exists for paper prices (INCAP) and for landfill costs (INCLFL). Forecasting the basic inflation rate is a perilous process, but for present purposes the interest rate for municipal bonds is used as the forecasted inflation rate. Many forecasts of energy prices assume that over the next 20 years these prices will increase about 3 percent faster than the Consumer Price Index. Wood prices have increased more sharply than the Producer Price Index since 1970 (but at a slower pace than energy prices), and the U.S. Forest Service expects this trend to continue for the rest of the century. Trends in landfill costs are very dependent upon location.

RRFSIZEA = Total Capacity of RRF These estimates should be stated in tons per year. This would include all garbage, including newsprint.

WNEWS = Source Separated-Newsprint as Percent for Total Garbage Flow On a nationwide basis, newsprint accounts for 7 percent of the solid waste stream. This represents the upper limit of what could be collected and sold. In practice some waste newsprint is already collected in paper drives. Furthermore, uncooperative consumers may refuse to source-separate their waste newsprint. The city can substantially increase source separation through public relations, police enforcement, and/or refusal to collect unseparated garbage. The amount of source-separated waste newsprint collected should be expected to range between 0 percent and 5 percent of total garbage collection. If the municipality passes and enforces a "flow control" ordinance and makes a serious effort to encourage source-separation of newsprint, then it should be at the higher end of this range. Conversely, if a municipality has no flow control and does not intend to strongly encourage source-separation, then it will be near the low end of the range.

Capacity Utilization Rates for RRF's In practice, very few RRF's operate at 100 percent of their expected output. Four categories of unscheduled problems which have caused low capacity utilization rates are:

1) insufficient solid waste delivered to RRF;

2) operating difficulties;

3) inability to generate as much salable steam per ton of garbage as had been expected; and

4) inability to sell as much steam as the facility could produce.

For the sake of simplicity, the model uses one measure of efficiency to encompass all four types of operating inefficiencies. The efficiency measure is the ratio of actual output sold (in pounds of steam) to full-capacity output (in pounds of steam). A review of operating RRF's showed that many of them were operating at well below expected capacity. A RRF using source-separated newsprint as a supplementary fuel would probably achieve an efficiency rate 5 to 10 percent higher than a RRF which does not use a supplementary fuel.

LDGrowth = Annual Rate of Growth in Solid Waste Flow Resource recovery facilities are often oversized to accommodate expected growth. If this is the case, then the projected annual growth rate should be entered as a decimal. If no growth is projected in the waste flow to be handled by the RRF, then zero should be entered here.

In some cases "loadgrowth" would be in increments, as modules are added to the RRF. Through skillful manipulation of the model, this situation could be simulated in large part, although some hand calculations would be required.

FLOW = Flow of Solid Waste in First Year, in tons per year This refers to all post-consumer solid waste, including source separatable newspapers. If this value is not known, enter zero and the computer will calculate this on the basis of population and estimated pounds of garbage per day per capita.

POP = Population to be Served by Proposed RRF These input data are only needed if the flow is not known. If flow is already known, enter zero.

LBCAP = Pounds of Garbage Generated per Capita per Day These input data are only needed if the total garbage flow is not known. If flow is already known, enter zero.

On a national average basis, it is estimated that 4.2 pounds of postconsumer waste is generated per person per day. Although this can usually be used as a preliminary estimate, the quantity and composition of garbage vary widely among communities.

Description of the Computer Program

The economic simulation model is programmed in the Statistical Analysis System language (SAS), which requires an IBM-compatible computer. [Commerce Department users can quickly access the program through the National Institutes of Health ADP system. Use of the NIH system requires a rudimentary understanding of WYLBUR.]

The program is listed in Exhibit 1. It is set up to process data entered in batches added after line 118.

Although there are 29 input data cells, only 26 or 27 items actually need to be entered. This is because the program is designed to estimate the size and cost of the facility if this information is not already known. Thus, if FLOW, CONCOSTA, and RRFSIZEA are not known, enter zero for these values and enter data for POP and LBCAP. The computer will then estimate the size and cost of the RRF based on construction cost of $55,000 per ton/day, which was the national average in 1980. Conversely, if FLOW, CONCOSTA and RRFSIZEA are known, then enter the data for these values and enter zero for POP and LBCAP. The computer will then estimate the size and cost of the RRF based on a construction cost of $55,000 per ton/day, which was the national average in 1980.

Lines 1 through 3 of the program are system cards relating to the NIH computer system.

Lines 4 through 8 describe the input set and the names of the 29 variables. Each input data card must have data in exactly the same order as shown in lines 6 through 8. (The actual data are not entered until after line 118.)

Lines 9 through 15 are data clean-up operations. These lines are necessary because the program is designed to calculate FLOW, RRFSIZEA, and CONCOSTA, if these values have not been developed in advance. Line 10 calculates SSNP, the volume of source separatable waste newspapers, based on FLOW and WNEWS. Line 13 calculates the size of the smaller RRF that would be required if waste newspapers were separated out of the garbage.

Lines 16 and 19 calculate the annual principal and interest payments on the RRF for each year of its 20-year life. The formula is a standard equation used in calculating fixed-payment mortgages.

Lines 20 through 28 are housekeeping steps which clear nine data registers that will be used to keep running totals.

Lines 29 through 30 instruct the computer to perform the large subroutine (on lines 31 through 116) twenty times. This subroutine calculates the economics of each option for year N (1,...20).

Lines 31 through 35 calculate changes that occur in the dynamic variables OPMANAN, SPRICEN, FLOWN, and SSNPN over the 20-year life of the RRF.

Lines 36 through 38 calculate the net energy revenue per ton of source-separated newsprint burned in a RRF as back-up fuel if the RRF operates at 100 percent of capacity. Line 36 calculates the in-plant generating costs per ton of steam from burning SSNP. Line 38 calculates the net energy revenue per ton of SSNP burned, if the RRF operates at 100 percent of capacity.

Lines 39 through 41 calculate the net energy revenue per ton of unseparated newsprint burned, if the RRF is operating at 100 percent of capacity. The methodology is very similar to that described in lines 36 through 38.

Lines 42 though 46 calculate the net energy revenue per ton of garbage from which SSNP has been separated, if the RRF is operating at 100 percent of capacity. The output from these calculations, ENREVZ, will be used to calculate benefits from a RRF which uses SSNP as a back-up fuel (a type B RRF).

Lines 47 through 52 calculate the net energy revenue per ton of garbage other than SSNP, if the RRF is operating at 100 percent of capacity. This differs from the calculation in lines 42 through 46 in that this situation refers to a RRF which burns garbage from which SSNP has been removed and which uses no back-up fuel (a type A RRF).

Lines 53 through 57 calculate the net energy revenue per ton of garbage other than SSNP, if the RRF is operating at 100 percent of capacity. This differs from the calculation in lines 47 through 52 in that this situation refers to a type A RRF which burns all garbage, including all newspapers with no source separation, without back-up fuel. Thus, in this case the energy value of the garbage is slightly higher and the size of the RRF is slightly larger, because source-separatable newspapers are included in the garbage.

Lines 58 through 68 calculate changes that occur in eleven dynamic variables over the 20-year life of the RRF. In all eleven cases, the cause of the changes is price inflation expected over the twenty years.

Lines 69 through 71 calculate BURNZ, which is the benefit per ton of source-separatable newspaper burned as back-up fuel in a RRF. This value differs from ENREVZ in that it incorporates the costs of operating at less than 100 percent of capacity as well as transportation costs, collection costs, and source separation costs.

Lines 72 and 73 calculate BURNY, which is the benefit per ton of unseparated newspaper which is burned in a RRF along with the rest of the garbage. Although there are no source separation costs and the collection costs are lower, the energy value per ton is less and the operating rate is lower.

Lines 74 through 76 calculate BURNX, which is the benefit per ton of garbage (other than SSNP) burned with SSNP as back-up fuel. (Type B RRF.)

Lines 77 through 79 calculate BURNW, which is the benefit per ton of garbage burned in a RRF with SSNP removed at the source and recycled to paper mills. (Type A RRF.)

Lines 80 through 82 calculate BURNV, which is the benefit per ton of garbage (other than SSNP) burned, with no back-up fuel and with unseparated newspapers included in the garbage. (Type A RRF.)

Lines 83 through 87 calculate the total dollar benefits per year in current dollars for each of the five options considered by the model. In the ALLDFL option all garbage and newspapers are landfilled. In the PRGLF option, source separatable newspapers are recycled and the remaining garbage is burned without back-up fuel (Type A RRF). In the ALBRNB option source separated newspapers are burned as back-up fuel along with the remaining garbage (Type B RRF). In the ALBRNA option newspapers are not source-separated, but rather all garbage is burned unseparated in RRF without back-up fuel (Type A RRF).

Lines 88 through 97 convert nine of the most important products from current dollar value to discount present value.

The elaborate procedure steps in lines 98 through 115 are necessary to calculate an average present value for each of the five options over the 20-year life of the RRF. Lines 98 through 106 keep a running total of nine variables which a discounted present value is calculated in lines 88 through 97. Lines 107 through 115 calculate the present value divided by 20, which are meaningless numbers for the first 19 years but in the 20th year these values become the average present value of each variable over the 20-year life of the RRF.

Input data are entered after line 118. Each data "card" contains 29 variables and must be entered in three lines in exactly the same order as in lines 6 through 8. The gap between lines 118 and 149 is large enough to handle batches of 10,000 "cards" at a time.

Lines 149 through 153 contain two SAS procedure steps. The first procedure step sorts the data by case. As used here a "case" is a set of assumptions, which is represented by one data "card" (3 physical cards).

Lines 150 through 153 instruct the computer to print ten data items for each of the 20 years for each case. The ten data items are the net benefits for each of the five disposal alternatives, expressed first in current dollars and second in discounted dollars.

Lines 154 through 156 are data development steps which instruct the computer to output "bottom line" estimates for only the 20th year of RRF life. As was discussed earlier, for the first 19 years this data is meaningless and could be confusing if it were printed.

Lines 157 through 159 instruct the computer to print the "bottom line" for each of the five options for each case.

EXHIBIT I

Source Listing of Program

```
//PACBURN JOB (WFP1,M924,A),MACAULEY
//PROCLIB DD DSN=ZABCRUN.PROCLIB,DISP=SHR
//STP1 EXEC SAS,SORT=80
//SYSIN DD *
DATA MSW;
INPUT
RRFSIZEA CONCOSTA FLOW LDGROWTH  POP LBCAP WNEWS ENUSMSW ENSSNP ENUSNP
SPRICE FPRICE LFLCOS CONVEFF OPRATEA OPRATEB OPMAINA TRLDFL TRMILL TRENR
TRXX CSEP CCOL INTRATE DISRATE RINF INCEN INCPAP INCLAND ;
               IF FLOW = 0 THEN FLOW = POP * LBCAP * .183;
               SSNP = WNEWS * FLOW;
               IF RRFSIZEA = 0 THEN RRFSIZEA =
                    (POP * LBCAP / 2000) * (1+ LDGROWTH)**20;
               RRFSIZEB = RRFSIZEA * ((FLOW - SSNP) / FLOW);
               IF CONCOSTA = 0 THEN CONCOSTA = RRFSIZEA * 55000;
               CONCOSTB = CONCOSTA * ((FLOW - SSNP) / FLOW);
MORTA = CONCOSTA * (((1 + INTRATE)**20)/
(((1 + INTRATE)**20) -1)) * INTRATE ;
MORTB = CONCOSTB *  (((1 + INTRATE)**20)/
(((1 + INTRATE)**20) -1)) * INTRATE;
TBURNZ = 0 ;
TBURNY = 0;
TLCOST = 0 ;
TPVAL = 0 ;
TALLDFL = 0;
TPRGLF = 0;
TPRGBA = 0;
TALBRNA = 0;
TALBRNB = 0;
CASE = _N_;
DO N = 1 TO 20;
OPMANAN = OPMAINA * (1+ RINF) ** (N-1);
SPRICEN = SPRICE * (1+(RINF + INCEN)) ** (N-1);
FLOWN = FLOW * (1 + LDGROWTH) ** (N-1);
SSNPN = SSNP * (1+ LDGROWTH)**(N-1);

STEAMZ = FLOWN * ENSSNP * CONVEFF * OPRATEB;
GENCOSZ = (MORTA + (OPMANAN * FLOWN )) / STEAMZ;
ENREVZ = ENSSNP * CONVEFF * (SPRICEN - GENCOSZ);
STEAMY = FLOWN * ENUSNP * CONVEFF * OPRATEA;
GENCOSY = (MORTA + (OPMANAN * FLOWN)) / STEAMY;
ENREVY = ENUSNP * CONVEFF * (SPRICEN - GENCOSY);
STEAMX = FLOWN * (ENUSMSW - (( SSNPN / FLOWN) * ENUSNP ))
          * CONVEFF * OPRATEB ;
GENCOSX = (MORTA + (OPMANAN * FLOWN )) / STEAMX;
ENREVX = (ENUSMSW - ((SSNPN / FLOWN) * ENUSNP))
           * CONVEFF * (SPRICEN - GENCOSX);
STEAMW = (FLOWN - SSNPN) * (ENUSMSW - ((SSNPN / FLOWN) * ENUSNP))
         * CONVEFF * OPRATEA ;
GENCOSW =  (MORTB + (OPMANAN * (FLOWN - SSNPN)))
          / STEAMW ;
```

```
ENREVW = (ENUSMSW - ((SSNPN / FLOWN) * ENUSNP))
          * CONVEFF * (SPRICEN - GENCOSW) ;
STEAMV = FLOWN * ( ENUSMSW - (( SSNPN / FLOWN) * ENUSNP))
          * CONVEFF * OPRATEA;
GENCOSV = (MORTA + ( OPMANAN * FLOWN)) / STEAMV;
ENREVV = (ENUSMSW - (( SSNPN / FLOWN ) * ENUSNP))
       * CONVEFF  * (SPRICEN - GENCOSV);
LFLCOSN = LFLCOS * (1 + RINF + INCLAND) ** (N-1);
TRLDFLN = TRLDFL * (1 + RINF)** (N-1);
TRXXN = TRXX * ( 1 + RINF ) ** (N-1) ;
PPRICEN = PPRICE * (1 + RINF + INCPAP) ** (N-1);
CSEPN = CSEP * (1 + RINF) ** (N-1);
CCOLN = CCOL * (1 + RINF) ** (N-1);
TRMILLN = TRMILL * (1 + RINF)**(N-1);
LCOST = -(LFLCOSN + TRLDFLN);
PVAL = PPRICEN - (CSEPN + CCOLN)
       + (LFLCOSN + TRLDFLN) - (TRMILLN);
TRENRN  = TRENR * ( 1 + RINF + INCEN) ** (N-1) ;
BURNZ = (OPRATEB * ( ENREVZ
       - (CSEPN + CCOLN + TRENRN))) -
        (( 1 - OPRATEB) * (LFLCOSN + TRLDFLN));
BURNY = (OPRATEA * (ENREVY   - TRENRN ))
         -(( 1 - OPRATEA) * (LFLCOSN + TRLDFLN));
BURNX = (OPRATEB * (ENREVX   - TRENRN ))
       - ( .2 * OPRATEB * ( LFLCOSN + TRXXN) + (( 1 - OPRATEB )
* (LFLCOSN + TRLDFLN )));
BURNW = (OPRATEA * (ENREVW     - TRENRN ))
       - ( .2 * OPRATEA * ( LFLCOSN + TRXXN ) + ((1 - OPRATEA)
* (LFLCOSN + TRLDFLN))) ;
BURNV = (OPRATEA * (ENREVV     - TRENRN ))
         - (.2 * OPRATEA * ( LFLCOSN + TRXXN ) + ((1 - OPRATEA )
* ( LFLCOSN +  TRLDFLN )));
ALLDFL = FLOWN * LCOST ;
PRGLF = (SSNPN * PVAL) + ((FLOWN - SSNPN) *LCOST);
PRGBA = (SSNPN * PVAL ) + ((FLOWN - SSNPN) * BURNW);
ALBRNA = (SSNPN * BURNY)  + ((FLOWN - SSNPN) * BURNV) ;
ALBRNB = (SSNPN * BURNZ) + ((FLOWN - SSNPN ) * BURNX ) ;
DRN = ( 1 + DISRATE)** (N-1);
DBURNZ = BURNZ / DRN;
DBURNY = BURNY / DRN;
DLCOST = LCOST / DRN;
DPVAL =  PVAL / DRN;
DALLDFL = ALLDFL / DRN ;
DPRGLF = PRGLF / DRN ;
DPRGBA = PRGBA / DRN ;
DALBRNA = ALBRNA / DRN ;
DALBRNB = ALBRNB / DRN ;
TBURNZ = DBURNZ + TBURNZ ;
TBURNY = DBURNY + TBURNY ;
TLCOST = DLCOST + TLCOST ;
TPVAL = DPVAL + TPVAL ;
TALLDFL = DALLDFL + TALLDFL ;
TPRGLF = DPRGLF + TPRGLF ;
TPRGBA = DPRGBA + TPRGBA ;
TALBRNA = DALBRNA + TALBRNA ;
TALBRNB = DALBRNB + TALBRNB ;
ALCOST = TLCOST / 20 ;
```

```
APVAL =  TPVAL / 20 ;
ABURNZ = TBURNZ / 20 ;
ABURNY = TBURNY / 20 ;
AALLDFL = TALLDFL / 20 ;
APRGLF = TPRGLF / 20 ;
APRGBA = TPRGBA / 20 ;
AALBRNA = TALBRNA / 20 ;
AALBRNB = TALBRNB / 20 ;
OUTPUT MSW;
END;
CARDS;
0 0 0 .02 100000 4.2 .02 9 14 10
3 66 10 .65 .8 .9 17.45 6 12 6 3
0 5 .12 .12 .10 .03 0 0
PROC SORT DATA=MSW ; BY CASE;
PROC PRINT DATA=MSW ;    VAR ALLDFL PRGLF PRGBA ALBRNA ALBRNB
        DALLDFL DPRGLF DPRGBA DALBRNA DALBRNB ;
TITLE LANDFILL COSTS VS PAPER RECYCLING VS BURNING FOR ENERGY;
BY CASE;
DATA T50 (KEEP = AALLDFL APRGLF APRGBA AALBRNA AALBRNB CASE);
SET MSW ;    BY CASE;
IF LAST.CASE  = 1 THEN OUTPUT T50;
PROC PRINT;VAR CASE AALLDFL APRGLF APRGBA AALBRNA AALBRNB ;
BY CASE;
TITLE LANDFILL COSTS VS PAPER RECYCLING VS BURNING FOR ENERGY;
/*
//
```

Results of the Economic Simulations

As a starting point for analyzing the subject, a "typical" resource recovery facility was simulated as the "base case." Although there are substantial variations among RRF's, the base case situation can provide valuable insights and serves as a frame of reference for analyzing other situations. Table 4 indicates the specific values of the variables assumed in the base case.

The results of the simulation for the base case are shown in table 5. All five options show net losses under base case assumptions. The costs per year for each of the five disposal alternatives are shown over the 20-year life of the facility. Given base-case assumptions, the most economical alternative for the first 13 years is to recycle source separated newspapers and dispose of the rest of the garbage in landfills. During the last 7 years the most economical alternative is burning all trash in the resource recovery facility and using newspapers as back-up fuel. The most economical strategy over the 20 years is determined by comparing the average present value over the 20-year span. In the base case the most economical alternative is recycle newspapers and landfill the remaining garbage.

It is noteworthy that all five options yield negative financial benefits under the base case conditions. The most economical alternative is the one which costs the least. (These costs would have to be defrayed by tipping fees, general revenues, or default on the bonds.) Under the optimistic assumptions, there are situations in which RRF's can yield positive financial benefits. In any event which ever method manages garbage at the least cost is the most economical option.

In addition to the base case scenario there are numerous other possible scenarios. The principal significant variations are likely to be site-specific. Seventy variations, covering the most likely differences from the base case, were examined during the sensitivity analysis. As might be expected, differing assumptions produce different outcomes.

Sales Price of Steam

The single most significant variable in selecting an option alternative is the sales price of steam. The base case assumed \$3/1000 pounds of steam, with variations to the base case from \$1 to \$10. The base case price of \$1 per thousand lbs. of steam would not make a recovery facility competitive with source separation of paper and landfilling. However, a sales price of \$4.00 per 1000 pounds could make recovery facility the preferred option. The price for which a municipality can sell its steam is determined by circumstances unique to each situation. Seven communities have considered proposals that included estimates of steam prices ranging from \$2 to \$13.70 per thousand pounds[6].

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[6] Unpublished Staff Report, Technical Advisory Center, Office of Recycled Materials of a survey of proposals submitted to the U.S. Environmental Protection Agency under the President's Urban Grant Program, 1981.

Table 4. Base Case Assumptions

	Variable Name	Base Case Value	Brief Description
1.	RRFSIZEA	0	Capacity of RRF, in tons of garbage per day
2.	CONCOSTA	0	Constructed cost of RRF, in dollars
3.	FLOW	0	Daily flow of garbage in first year, tons
4.	LDGROWTH	.02	Annual loadgrowth factor, if oversized RRF
5.	POP	100,000	Population served by RRF in first year
6.	LBCAP	4.2	Garbage generated per capita, in pounds per day
7.	WNEWSA	.02	Source-separatable newspaper as fraction of garbage
8.	ENUSMSW	9	Energy content of separated garbage, million-Btu's/ton
9.	ENSSNP	14	Energy content of separated garbage, million-Btu's/ton
10.	ENUSNP	10	Energy content of unseparated newspapers, million-Btu's/ton
11.	SPRICE	2	Sales price of steam, $per 1000 lbs., first year
12.	PPRICE	66	Sales price of newspapers, $per ton, first year
13.	LFLCOS	10	Landfill cost, $per ton, first year
14.	CONVEFF	.65	Conversion efficiency of boiler, fraction
15.	OPRATEA	.8	Operating rate for RRF without back-up fuel, fraction

Base Case Assumptions

	Variable Name	Base Case Value	Brief Description
16.	OPRATEB	.9	Operating rate for RRF, newspapers as back-up fuel, fraction
17.	OPMAINA	17.45	Operating and maintenance costs per ton of garbage (Based on an underutilization of capacity
18.	TRLDFL	6	Transportation costs to landfill, $per ton
19.	TRMILL	12	Transportation costs to paper mill, $per ton
20.	TRENR	6	Transportation costs to RRF, $per ton
21.	TRXX	3	Transportation costs from RRF to landfill, $per ton
22.	CSEP	0	Cost per ton of source separating newspapers
23.	CCOL	5	Extra costs per ton of collecting newspapers
24.	INTRATE	.12	Interest rate on bonds to finance RRF
25.	DISRATE	.12	Rate used to discount the value of future dollars
26.	RINF	.10	Average annual rate of inflation over 20 years
27.	INCEN	.03	Incremental inflation rate for energy prices
28.	INCPAP	0	Incremental inflation rate for paper prices
29.	INCLFL	0	Incremental inflation rate for landfill costs

Table 5. Hypothetical 312 Tons-Per-Day Solid Waste Disposal Strategies.
Results of the Economic Simulations for the Base Case
(net benefits, dollars per year)

	Current Dollars					Discounted Dollars				
Year	All Garbage Land-filled (ALLDFL)	Paper Recycled, Other Garbage Land-filled (PRGLF)	Paper Recycled, Garbage to RRF, no backup fuel (PRGBA)	All Garbage to RRF no backup fuel (ALBRNA)	All Gargabe to RRF, paper as backup fuel (ALBRNB)	All Garbage Land-filled (ALLDFL)	Paper Recycled, Other Garbage Land-filled (PRGLF)	Paper Recycled Garbage to RRF, no backup fuel (PRGBA)	All Garbage to RRF, no backup fuel (ALBRNA)	All Garbage to RRF, paper as backup fuel (ALBRNB)
1	-1229760	-1105247	-3191453	-3352467	-3159066	-1229760	-1105247*	-3191453	-3352467	-3159066
2	-1379791	-1240087	-3285517	-3460060	-3240098	-1231956	-1107220*	-2933497	-3089339	-2892945
3	-1548125	-1391378	-3387917	-3577562	-3327346	-1234156	-1109198*	-2700826	-2852010	-2652540
4	-1736996	-1561126	-3499189	-3705690	-3421007	-1236360	-1111178*	-2490654	-2637637	-2435006
5	-1948910	-1751583	-3619866	-3845175	-3521220	-1238568	-1113163*	-2300490	-2443678	-2237799
6	-2186677	-1965276	-3750457	-3996751	-3628038	-1240779	-1115150*	-2128110	-2267864	-2058646
7	-2453452	-2205040	-3891437	-4161140	-3741411	-1242995	-1117142*	-1971523	-2108163	-1895515
8	-2752773	-2474055	-4043230	-4339038	-3861148	-1245215	-1119137*	-1828952	-1962761	-1746587
9	-3088611	-2775889	-4206178	-4531096	-3986888	-1247438	-1121135*	-1698805	-1830034	-1610237
10	-3465422	-3114548	-4380521	-4737890	-4118050	-1249666	-1123137*	-1579660	-1708531	-1485010
11	-3888203	-3494522	-4566352	-4959889	-4253782	-1251897	-1125143*	-1470243	-1596952	-1369604
12	-4362564	-3920854	-4763580	-5197421	-4392895	-1254133	-1127152*	-1369416	-1494134	-1262852
13	-4894797	-4399198	-4971877	-5450617	-4533793	-1256372	-1129165*	-1276157	-1399038	-1163712
14	-5491962	-4935901	-5190609	-5719356	-4674375	-1258616	-1131181	-1189554	-1310729	-1071246*
15	-6161981	-5538080	-5418764	-6003193	-4811932	-1260863	-1133201	-1108786	-1228372	- 984617*
16	-6913743	-6213726	-5654857	-6301270	-4943015	-1263115	-1135225	-1033121	-1151219	- 903070*
17	-7757219	-6971801	-5896821	-6612214	-5063285	-1265371	-1137252	- 961899	-1078595	- 825932*
18	-8703600	-7822361	-6141872	-6934008	-5167335	-1267630	-1139283	- 894529	-1009899	- 752593*
19	-9765439	-8776689	-6386354	-7263842	-5248468	-1269894	-1141317	- 830479	- 944587	- 682509*
20	-10956823	-9847445	-6625547	-7597935	-5298458	-1272161	-1143355	- 769271	- 882172	- 615187*
Average Annual Benefits										
	(X)	(X)	(X)	(X)	(X)	(ALLDFL) -1,251,000	(PRGLF) -1,124,000*	(PRGBA) -1,686,000	(ALBRNA) -1,817,000	(ALBRNB) -1,590,000

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*Least-cost option: Assumes $66 per ton of paper.

On average, a large industrial customer with an existing coal-fired steam system has a fuel cost of about 96¢ per thousand pounds of steam (at $25/ton coal, 90 percent efficiency in 1981); and, therefore, would be very reluctant to buy steam at a higher price. (See table 6.) A customer with a serious pollution problem, space problem, or capital problem may be willing to pay more, but this type of customer may not be a good candidate for a 20-year sales contract. The base case value of $3 per 1000 pounds of steam would thus seem to be on the high side, but a number of municipalities have indicated they can sell their output at even higher prices.

Construction Costs

The construction cost per ton/day of garbage-burning capacity varies widely among steam-producing RRF's, from $13,000 to $78,000 in 1980 dollars. Table 7 indicates that plants at the low end of this cost range would tend to be competitive with landfill, while the average cost facility ($50,000 per ton/day capacity) would not. Facilities at the high end of the construction cost range would incur a loss more than twice the cost of landfilling.

Landfill Costs

Landfill costs are a major determinant of the viability of recovery planning. Where landfill costs are greater than $18 per ton, recovery tends to be more economical. (See table 8.) The cost of landfill as used in the simulation model is a gross cost which does not net out the revenues from tipping fees. (Since tipping fees are often determined by political factors as well as cost factors, and since tipping fees would be charged by both landfills and RRF's, the inclusion of tipping fees in the equations would complicate the model without significantly increasing its usefulness.)

Operating and Maintenance Costs

Operating and maintenance (O&M) costs are a significant factor in resource recovery economics. A survey of six RRF's indicated an average O&M cost of $17.45 per ton of garbage burned[7]. Under base-case conditions a RRF which kept O&M costs below $10 per ton would be more economical than a landfill. (See table 9.) Although none of he six facilities surveyed had O&M costs below $12 per ton, operating experience and innovation could possibly reduce these costs.

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[7] U.S. Conference of Mayors, City Currents: Special Issue, March 29, 1982.

Table 6. Sensitivity of Decision Model to Sales Price of Steam

Sale Price of Steam (per 1000 pounds) (SPRICE)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 1.00 SPRICE	-$1,251,000	-$1,124,000	-$2,604,000	-$2,756,000	-$2,656,000
2.00 SPRICE	-$1,251,000	-$1,124,000	-$2,145,000	-$2,287,000	-$2,123,000
2.50 SPRICE	-$1,251,000	-$1,124,000	-$1,916,000	-$2,052,000	-$1,857,000
3.00 SPRICE (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
3.50 SPRICE	-$1,251,000	-$1,124,000	-$1,457,000	-$1,583,000	-$1,324,000
4.00 SPRICE	-$1,251,000	-$1,124,000	-$1,228,000	-$1,348,000	-$1,057,000
5.00 SPRICE	-$1,251,000	-$1,124,000	-$ 769,000	-$ 878,000	-$ 524,000
6.00 SPRICE	-$1,251,000	-$1,124,000	-$ 310,000	-$ 409,000	+$ 8,800
7.00 SPRICE	-$1,251,000	-$1,124,000	+ 149,000	+$ 61,000	+$ 542,000
10.00 SPRICE	-$1,251,000	-$1,124,000	+$1,526,000	+$1,469,000	+$2,141,000

Table 7. Sensitivity of Decison Model to RRF Construction Costs

Construction Cost of 312 tpd RRF (in 1980 dollars) CONCOSTA	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 6,865,000 CONCOSTA ($22,000/tpd)	-$1,251,000	-$1,124,000	-$1,121,000	-$1,241,000	-$1,014,000
$ 7,801,000 CONCOSTA ($25,000/tpd)	-$1,251,000	-$1,124,000	-$1,173,000	-$1,293,000	-$1,065,000
$ 8,738,000 CONCOSTA ($28,000/tpd)	-$1,251,000	-$1,124,000	-$1,224,000	-$1,346,000	-$1,118,000
$ 9,361,000 CONCOSTA ($30,000/tpd)	-$1,251,000	-$1,124,000	-$1,258,000	-$1,381,000	-$1,153,000
$12,482,000 CONCOSTA ($40,000/tpd)	-$1,251,000	-$1,124,000	-$1,429,000	-$1,555,000	-$1,328,000
$17,162,750 CONCOSTA (Base Case)($55,000/tpd)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
$18,723,000 CONCOSTA ($60,000/tpd)	-$1,251,000	-$1,124,000	-$1,772,000	-$1,905,000	-$1,678,000
$24,964,000 CONCOSTA ($80,000/tpd)	-$1,251,000	-$1,124,000	-$2,115,000	-$2,254,000	-$2,027,000
$31,205,000 CONCOSTA ($100,000/tpd)	-$1,251,000	-$1,124,000	-$2,457,000	-$2,604,000	-$2,377,000
$39,942,000 CONCOSTA ($128,000/tpd)	-$1,251,000	-$1,124,000	-$2,936,000	-$3,093,000	-$2,866,000

Table 8. Sensitivity of Decision Model to Landfill Costs

Landfill Costs per ton of Garbage Dumped (LFLCOS)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 5 LFLCOS	-$ 860,000	-$ 749,000	-$1,556,000	-$1,678,000	-$1,482,000
$10 LFLCOS (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
$15 LFLCOS	-$1,642,000	-$1,499,000	-$1,816,000	-$1,957,000	-$1,698,000
$18 LFLCOS	-$1,876,000	-$1,725,000	-$1,895,000	-$2,041,000	-$1,763,000
$19 LFLCOS	-$1,954,000	-$1,800,000	-$1,921,000	-$2,068,000	-$1,785,000
$20 LFLCOS	-$2,033,000	-$1,875,000	-$1,947,000	-$2,096,000	-$1,806,000

Table 9. Sensitivity of Decision Model to Operating and Maintenance Costs

	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
Operating and Maintenance cost per ton of Garbage Burned (OPMAINA)	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 8.73/ton	-$1,251,000	-$1,124,000	-$1,018,000	-$1,136,000	-$ 909,000
$10.00/ton	-$1,251,000	-$1,124,000	-$1,116,000	-$1,235,000	-$1,008,000
$12.00/ton	-$1,251,000	-$1,124,000	-$1,269,000	-$1,391,000	-$1,164,000
$13.00/ton	-$1,251,000	-$1,124,000	-$1,345,000	-$1,470,000	-$1,242,000
$14.00/ton	-$1,251,000	-$1,124,000	-$1,422,000	-$1,548,000	-$1,321,000
$15.00/ton	-$1,251,000	-$1,124,000	-$1,499,000	-$1,626,000	-$1,399,000
$17.45/ton (Base Case)	-$1,251,000	-$1,124,000	-$1,686,371	-$1,817,000	-$1,590,000
$20/ton	-$1,251,000	-$1,124,000	-$1,882,000	-$2,017,000	-$1,790,000
$26.26/ton	-$1,251,000	-$1,124,000	-$2,357,000	-$2,501,000	-$2,274,000

Operating Rates

Operating rates are expected capacity utilization rates with allowance for normal downtime[8]. Although high operating rates do not guarantee success, low operating rates can lead to economic disaster. Low operating rates, often associated with unreliability, not only lead to reduced sales of steam, but also result in high landfill costs in order to dispose of unburnt garbage. Many existing facilities operate at low rates, which has been one of the major reasons for their poor financial performance[9]. The base case assumes that a proposed facility would operate at 90 percent of capacity using newspapers as back-up fuel or 80 percent of capacity without back-up fuel.

As shown in table 10, a facility operating at 90 percent of capacity spends about 30 percent more per ton to dispose of garbage than does a landfill, while at a 60 percent operating rate the per-ton disposal cost for facility would be double the landfill cost. In addition to the financial costs of low operating rates are greater physical landfill requirements which increase from 28 percent to 52 percent of the garbage flow as the operating rate of the RRF declines from 90 percent to 60 percent.

The simulation model assumes that in the future fossil fuels such as natural gas and fuel oil would not be extensively used as a back-up fuel. It is currently a common practice to use these valuable resources to enhance burning during periods when wet or non-combustible garbage reduces burning efficiency. This not only increases operating costs, but negates much of the energy-saving benefits as well. A promising alternative is the use of dry source-separated newspaper as back-up fuel instead of fossil fuels. The model does not consider burning fossil fuels as auxiliary fuel.

The base case assumes that operating rate with source separated newspapers as a back-up fuel would be about 10 percent higher than operating without such back up fuel, although this level has not been demonstrated in an operating facility. If operating rates in either case are equal, then the costs are also about the same since the extra costs of separating and handling newspapers are offset by the extra energy value.

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[8] For example, if a RRF is expected to operate at 1000 tons per day for 360 days of the year, yet in fact experiences 36 days of unscheduled downtime plus 36 days of operating at only 500 tpd, then the operating rate would be 85 percent.

[9] Ronald J. Alvarex, Hofstra University. Status of Incineration and Generation of Energy From Thermal Processing of MSW. Proceedings of the 1980 National Waste Processing Conference.

Table 10. Sensitivity of Decision Model to Operating Rate of Resource Recovery Facility

Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies

(OPRATEA, OPRATEB)	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
.50, .60	-$1,251,000	-$1,124,000	-$2,330,000	-$2,477,000	-$2,252,000
.55, .60	-$1,251,000	-$1,124,000	-$2,223,000	-$2,367,000	-$2,252,000
.55, .65	-$1,251,000	-$1,124,000	-$2,223,000	-$2,367,000	-$2,142,000
.60, .65	-$1,251,000	-$1,124,000	-$2,116,000	-$2,257,000	-$2,142,000
.60, .70	-$1,251,000	-$1,124,000	-$2,116,000	-$2,257,000	-$2,032,000
.65, .70	-$1,251,000	-$1,124,000	-$2,008,000	-$2,147,000	-$2,032,000
.70, .80	-$1,251,000	-$1,124,000	-$1,901,000	-$2,037,000	-$1,811,000
.80, .80	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,811,000
.80, .90 (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
.85, .90	-$1,251,000	-$1,124,000	-$1,579,000	-$1,707,000	-$1,590,000
.90, .90	-$1,251,000	-$1,124,000	-$1,472,000	-$1,598,000	-$1,590,000
.90, .95	-$1,251,000	-$1,124,000	-$1,472,000	-$1,598,000	-$1,480,000
1.00, 1.00	-$1,251,000	-$1,124,000	-$1,257,000	-$1,378,000	-$1,370,000
.80, .70	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$2,032,000
.80, .60	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$2,252,000

OPRATEA: No backup; OPRTEB: Backup

Energy Conversion Efficiency

The conversion efficiency of the boiler is not likely to have a decisive effect on the economics of the RRF. (See table 11.) In light of the severe economic penalty for low operating rates, the municipality should be just as concerned, if not more so, with boiler reliability as with boiler efficiency.

A comparison of tables 10 and 11 shows that a change of one percentage point in efficiency costs about as much as a one percentage point change in operating rates. However, the downside range for operating rates is much broader, given existing technology. Thus, for a facility using backup fuel, a reduction in efficiency from 70 percent to 56 percent would cost $345,000 annually, while a reduction in operating rates (reliability) from 95 percent to 60 percent would cost $772,000 annually.

A RRF with the ironic combination of a 60 percent operating rate and 56 percent efficiency would annually cost $1,050,000 more than a RRF with a near-perfect combination of 95 percent operating rates and 70 percent efficiency.

Wastepaper Prices

Under base-case conditions, wastepaper prices are not a decisive factor in the decision to burn or landfill garbage. (See table 12.) The 1981 BIE survey of the wastepaper recycling industry in the Southeastern U.S. found that waste newspaper prices averaged $66 per ton, with the buyer usually paying freight[10]. Under these conditions recycling would be very attractive. However, the wastepaper market is subject to extreme price variability during a business cycle. In some cases waste newspapers cannot even be given away.

Wastepaper prices do become significant in situations where steam prices are substantially higher than the base case value of $3.00 per 1000 pounds of steam. For example, if the steam price was $4.00 per 1000 pounds, then wastepaper prices would have to be at least $110 per ton to make paper recycling preferable to burning. Figure 2 illustrates the more economical use of waste newspaper at various combinations of prices for wastepaper and steam and assuming base case conditions for all other variables. Under these conditions with steam prices less than $3.25 per 1000 pounds, paper recycling is preferable regardless of the wastepaper price, because the facility is losing money with steam prices at or below $3.25. With steam prices higher than $4.75 per 1000 pounds, wastepaper prices would have to exceed $200 per ton. (See table 13.)

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[10] Bureau of Industrial Economics, U.S. Department of Commerce; Waste Newspapers in Four South Atlantic States, 1980.

Table 11. Sensitivity of Decision Model to Conversion Efficiency of RRF

	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
(CONVEFF)	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
56% CONVEFF	-$1,251,000	-$1,124,000	-$1,877,000	-$2,012,000	-$1,812,000
65% CONVEFF (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
70% CONVEFF	-$1,251,000	-$1,124,000	-$1,580,000	-$1,709,000	-$1,467,000

Table 12. Sensitivity of Decision Model to Wastepaper Prices

Sales Price of Source-Separated Newspapers per ton (PPRICE)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 0 PPRICE	-$1,251,000	-$1,227,000	-$1,790,000	$1,817,000	-$1,590,000
$ 5 PPRICE	-$1,251,000	-$1,220,000	-$1,782,000	$1,817,000	-$1,590,000
$10 PPRICE	-$1,251,000	-$1,212,000	-$1,774,000	$1,817,000	-$1,590,000
$20 PPRICE	-$1,251,000	-$1,196,000	-$1,758,000	$1,817,000	-$1,590,000
$30 PPRICE	-$1,251,000	-$1,180,000	-$1,743,000	$1,817,000	-$1,590,000
$45 PPRICE	-$1,251,000	-$1,157,000	-$1,719,000	$1,817,000	-$1,590,000
$66 PPRICE (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	$1,817,000	-$1,590,000
$77 PPRICE	-$1,251,000	-$1,107,000	-$1,669,000	$1,817,000	-$1,590,000

Table 13. Sensitivity of Decision Model to Transportation Costs for Paper

Transportation Costs per ton of Source-Separated Newspapers, from Assembly point to Recycler	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 5 TRMILL	-$1,251,000	-$1,117,000	-$1,679,000	-$1,817,000	-$1,590,000
$ 7.50 TRMILL	-$1,251,000	-$1,113,000	-$1,675,000	-$1,817,000	-$1,590,000
$12 TRMILL (Base Case)	-$1,251,000	-$1,117,000	-$1,686,000	-$1,817,000	-$1,590,000
$15 TRMILL	-$1,251,000	-$1,129,000	-$1,691,000	-$1,817,000	-$1,590,000
$25 TRMILL	-$1,251,000	-$1,145,000	-$1,707,000	-$1,817,000	-$1,590,000
$35 TRMILL	-$1,251,000	-$1,160,000	-$1,722,000	-$1,817,000	-$1,590,000
$45 TRMILL	-$1,251,000	-$1,176,000	-$1,734,000	-$1,817,000	-$1,590,000

Steam costs of $4.00 per 1000 pounds are the exception rather than the rule in energy-intensive industrial operations. Therefore, an industrial customer paying these high steam prices may have difficulty remaining competitive in its field during the 20-year life of a recovery facility.

Transportation Costs

Within the most common cost ranges, transportation costs for waste newspapers are not by themselves a crucial determinant. However, in conjunction with low paper prices, high transportation costs could make recycling uneconomical. (See table 14.)

Special Source-Separation Costs

The extra costs of source-separating newspapers would not be great enough to determine the most economical use of wastepaper. The costs of source- separation are small relative to paper prices and transportation costs. The public inconvenience of source-separation is external to this analysis, although this could be an important consideration in some cases. (See table 15.)

Interest rates, present value discount rates, and inflation rates tend to move together, and thus are presented together in table 16. The higher the interest and discount rate the less attractive are recovery options. High inflation rates tend to make recovery options attractive if financing can be acquired at substantially lower rates than the rate of inflation.

In table 16 the present value discount rate is equal to the interest rate paid on municipal bonds. Although this probably conforms to common practice, a higher discount rate should normally be used to account for risk and reduction of the municipality's remaining borrowing power. Higher discount rates would tend to make recovery options even less economical than landfills and/or source separation.

Energy and Inflation Rates

Many recent economic forecasts assume that energy prices will increase faster than the overall inflation rate. The base case assumes that prices for energy will rise at an average annual rate of 3 percentage points above the overall inflation rate, and that steam sales contracts will have escalator clauses tying the price of steam to the price of alternate energy supplies. A variety of incremental energy inflation rates are simulated in table 15. Under base case conditions energy prices would have to increase annually 7 percent age points faster than the overall inflation rate during the twenty-year period to make the facility more economical than landfills. However, model users can input varying inflation rates. (See table 16.)

Table 14. Sensitivity of Decision Model to Extra Collection Costs for Source-Separated Newspapers

Extra Costs Per Ton of collecting Source-Separated Newspapers and/or Bringing them to Assembly Point CCOL	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
$ 5/ton (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,597,000
$10/ton	-$1,251,000	-$1,132,000	-$1,694,000	-$1,817,000	-$1,597,000
$20/ton	-$1,251,000	-$1,148,000	-$1,710,000	-$1,817,000	-$1,597,000

Table 15. Sensitivity of Decision Model to Energy Price Increases

Incremental Paper Price Inflation Rate Relative to Overall Inflation Rate During 20-Yr Life of RRF (INCEN)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
- 2% INCEN	-$1,251,000	-$1,124,000	-$2,005,000	-$2,143,000	-$1,962,000
0% INCEN	-$1,251,000	-$1,124,000	-$1,898,000	-$2,034,000	-$1,837,000
+ 2% INCEN	-$1,251,000	-$1,124,000	-$1,765,000	-$1,898,000	-$1,682,000
+ 3% INCEN (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
+ 5% INCEN	-$1,251,000	-$1,124,000	-$1,501,000	-$1,627,000	-$1,373,000
+ 6% INCEN	-$1,251,000	-$1,124,000	-$1,391,000	-$1,515,000	-$1,245,000
+ 7% INCEN	-$1,251,000	-$1,124,000	-$1,269,000	-$1,389,000	-$1,102,000
+ 8% INCEN	-$1,251,000	-$1,124,000	-$1,131,000	-$1,249,000	-$ 941,000
+10% INCEN	-$1,251,000	-$1,124,000	-$ 805,000	-$ 914,000	-$ 560,000

Table 16. Sensitivity of Decision Model to Interest Rates, Present Value Discount Rates, and Inflation Rates

Average Annual Rates (INTRATE,DISRATE,RINF)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
.07, .07, .07	-$1,494,000	-$1,343,000	-$1,763,000	-$1,914,000	-$1,639,000
.09, .09, .07	-$1,245,000	-$1,119,000	-$1,651,000	-$1,781,000	-$1,554,000
.12, .12, .10 (Base Case)	-$1,251,000	-$1,124,000	-$1,686,371	-$1,817,409	-$1,590,234
.14, .14, .12	-$1,255,000	-$1,128,000	-$1,710,000	-$1,841,000	-$1,614,000
.09, .09, .12	-$1,992,000	-$1,791,000	-$2,054,000	-$2,249,000	-$1,881,000
.09, .09, .15	-$2,697,000	-$2,424,000	-$2,431,000	-$2,689,000	-$2,186,000
.09, .09, .05	-$1,046,000	-$ 940,000	-$1,543,000	-$1,655,000	-$1,466,000
.12, .12, .05	-$ 831,000	-$ 747,000	-$1,454,000	-$1,548,000	-$1,400,000
.12, .12, 0	-$ 583,000	-$ 524,000	-$1,314,000	-$1,386,000	-$1,284,000

Landfill Inflation Rates

In some instances landfill costs have been increasing faster than the overall rate of inflation. This is more likely to be true for those landfills which have incurred exceptional costs resulting from environmental regulations or where land prices have soared. A large percentage of the cost of landfill can be fixed at the time the landfill site is acquired. Landfill O&M costs are not likely to increase much faster than the overall inflation rate except to the extent that new regulatory requirements increase costs. Tables 8 and 15 indicate that cost increases for landfilling would have to exceed the average annual inflation rate by 8 percent per year for 20 years to make recovery options more attractive than landfill under base case conditions.

Wastepaper Inflation Rates

The wastepaper price inflation rate has virtually no impact on the most desired alternative, under base case conditions and for steam prices of less than $3 per 1000 pounds. (See table 17). However, for medium-high paper prices and medium-high steam prices, this wastepaper inflation rate could become important.

Steam Prices vs. Landfill Costs

Steam prices and landfill costs are important variables in determining the most economical means of garbage disposal. (See table 18.) Therefore examination of these two variables together is in order. Assuming base case conditions for all other variables, figure 3 illustrates the results of the model at various combinations of steam prices and landfill costs. Recovery options become more attractive as landfill costs become higher. With landfill costs above $30 per ton, recovery facility would be economical even with steam prices as low as $1.00 per 1000 pounds. Similarly, with steam prices above $4.50 per 1000 pounds, recovery facility would be economical even if landfill costs were near zero. However, the great majority of the most likely combinations of steam prices and landfill costs are in the "LANDFILL" area of figure 3.

Table 17. Sensitivity of Decision Model to Wastepaper Price Increases

	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
Incremental Paper Price Inflation Rate Relative to Overall Inflation Rate During 20-Yr Life of RRF (INCPAP)	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
-2% INCPAP	-$1,251,000	-$1,140,000	-$1,702,000	-1,817,000	-$1,590,000
0% INCPAP (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
+2% INCPAP	-$1,251,000	-$1,104,000	-$1,666,000	-$1,817,000	-$1,590,000

Table 18. Sensitivity of Decision Model to Landfill Cost Inflation Rate

Incremental Landfill Cost Inflation Rate Relative to Overall Inflation Rate During 20-Yr Life of RRF (INCLFN)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
- 5% INCLFL	-$ 988,000	-$ 872,000	-$1,599,000	-$1,724,000	-$1,518,000
0% INCLFL (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000
+ 5% INCLFL	-$1,704,000	-$1,560,000	-$1,837,000	-$1,979,000	-$1,716,000
+ 8% INCLFL	-$2,127,000	-$1,965,000	-$1,978,000	-$2,130,000	-$1,832,000
+10% INCLFL	-$2,499,000	-$2,323,000	-$2,102,000	-$2,263,000	-$1,935,000

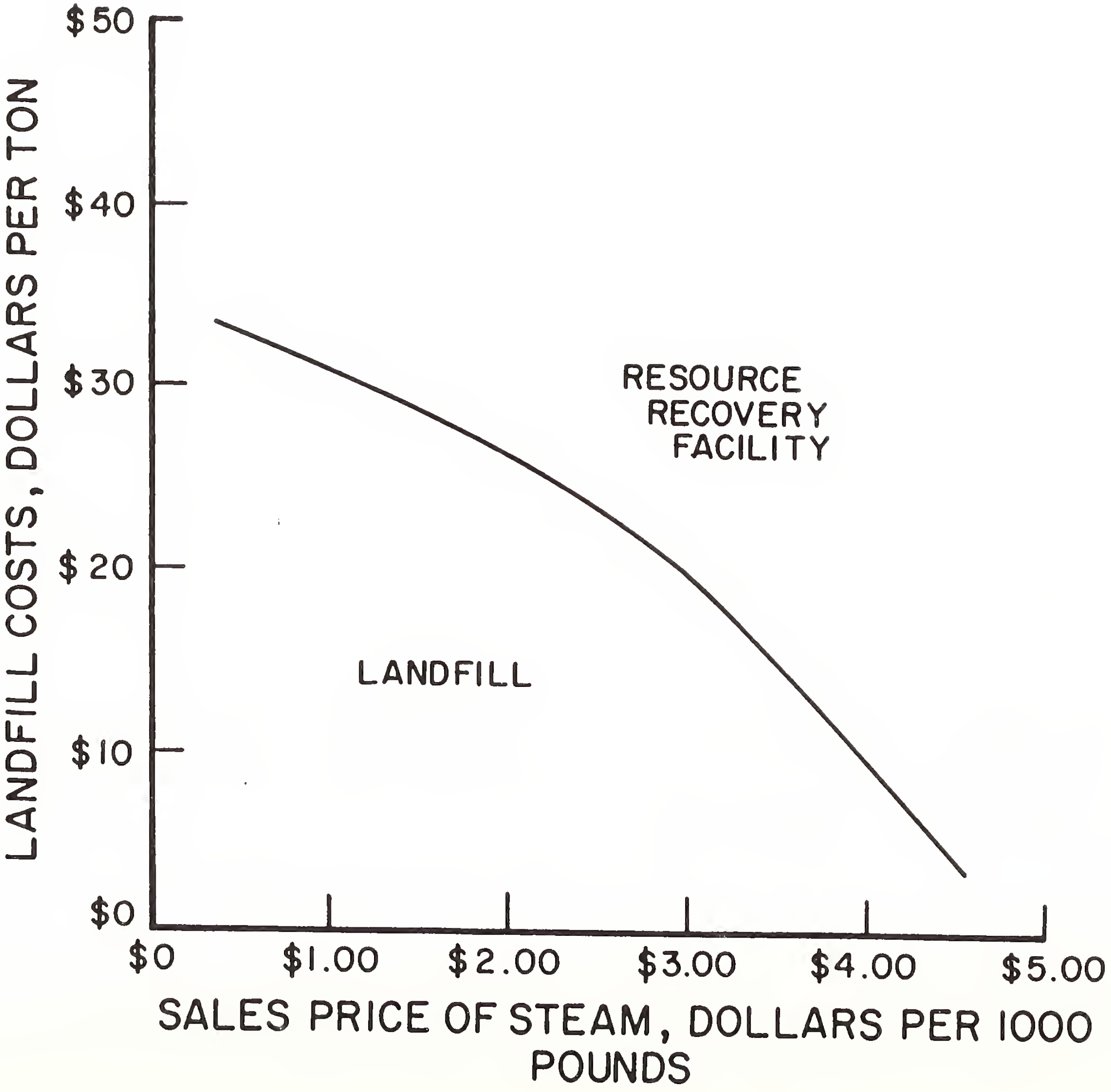

Figure 3. Trade-Off Prices for Garbage Disposal.

Table 19. Sensitivity of Decision Model to Overbuilding for Growth in Demands

(LDGROWTH)	Average Annual Present Value of Benefits from Alternative Solid Waste Management Strategies				
	All Solid Wastes Landfilled	Garbage Landfilled, Source-Separated Newspapers Recycled	Garbage Burned in RRF without Auxiliary Fuel, Source-Separated Newspapers Recycled	All Solid Waste Burned in RRF without Auxiliary Fuel	All Solid Waste Burned in RRF, using Source-Separated Auxiliary Fuel
BASE CASE CONDITIONS, Except:					
% LDGROWTH	-$1,042,000	-$ 936,000	-$1,267,000	-$1,373,000	-$1,186,000
2% LDGROWTH (Base Case)	-$1,251,000	-$1,124,000	-$1,686,000	-$1,817,000	-$1,590,000

References

[1] Determination of the Calorific Value of Refuse-Derived-Fuels by Large-Bomb Calorimetry, Summary of the 1978 Fiscal Year Results, D. R. Kirklin, E. S. Domalski, D. V. Mitchell, January 1980. (NBS-IR-80-1968)

[2] "Recent Federal Actions Which Will Affect Present Demands for Discarded Fibers", Presentation by Dr. Harvey Yakowitz to American Paper Institute. October 23, 1980.

[3] Test Procedures for the Determination of the Gross Calorific Value of Refuse and Refuse-Derived Fuel by Conventional Bomb and Large Bomb Calorimetry, D. R. Kirklin, J. Colbert, P. Decker, S. Abramowitz, E. S. Domalski, June 1981. (NBS-IR-81-2278)

[4] Thermodynamic Data for Waste Incineration, E. S. Domalski, W. H. Evan, T. L. Jobe, August 1978. (NBS-IR-78-1479)

APPENDIX XII. OVERVIEW OF RRPLAN

RRPlan is a computerized mathematical model developed for the study of solid waste systems. The computer program, or model, has been designed using a mathematical theory known as "linear programming." With this mathematical technique, it is possible to find the precise values of a set of variables that will optimize a specified function, usually a cost function. Thus, if the variable parameters are, e.g., site location, amount of paper recycled, modes and routes of transportation, etc., the linear programming technique will allow an analyst to determine the best choices for these parameters in order to cause a cost (or profit) function to assume a minimum (or maximum) value. This linear programming technique is designed to analyze linear functions, i.e., functions that can be approximated by using several linear functions in the same manner that a curve can be approximated by several straight lines. The RRPlan model uses up to three linear segments to approximate non-linear cost functions.

The user of the model may select one of four modes of operation:

1) Minimize cost, discounted and undiscounted.

2) Maximize net energy.

3) Minimize a linear combination of energy and cost.

4) Evaluate a specific plan.

Whatever mode of operation is selected, the output summary of the model provided in the computer printout will include discounted and undiscounted costs by type of cost and total, and net energy by category. For each cost, annual and lifetime measures are given and the discounted, undiscounted and energy requirement per ton of MSW is given.

The preferred plan chosen by RRPlan balances the cost of haul against the cost of larger facilities to derive the least cost optimal solution. In order to do this, the program considers many possible solutions in order to select the best choice. This optimal solution also indicates the best fit into the available markets for resource recovery or recycling. The cost of haul to market and the prices received at the market add to or reduce the cost of a possible solution.

The RRPlan may also be used to evaluate a single specific plan. In this case, the solution is known and the model merely describes the plan's cost and allocations and evaluates the future cost and overall efficiency through the input of financial data such as the interest rate and the discount rate.

The RRPlan solution will address the following questions:

1) What type of facilities should be used and where?

2) What are the most efficient capacities to handle the waste generated?

3) How much and by which mode of transportation should each community ship its waste to each facility?

4) Which recoverables should be marketed?

5) How much of each type of recoverable should be marketed and where?

6) What will the cost breakdown be?

The model analyzes the types of facilities such as landfill, transfer station, incinerator with heat recovery, modular incinerator, etc., and matches these with the different locations where they could be built or already exist. When locating a facility, the model uses such factors as proximity to the source of waste, the cost of that facility and the availability of markets. The model will then choose the optimum size of each facility and match that facility with the sources of waste generated.

The transportation linkages between the facilities (called sites) and the communities, or sources of waste (called sources), are determined by the model. These linkages will not only show how much but by which mode of transport wastes should be shipped. The different modes of transport are, for example, packers or large 18 wheel trucks. It is assumed that collection vehicles are homogenous types of vehicles, i.e., some sort of packer. When long hauls are necessary, the model will locate a transfer station at a source so as to decrease haul costs, making the haul from that source to a site by van instead of a packer.

Recoverables, glass, metal, and paper may be either source separated or taken out as part of a process at a facility. The distance to the market for these commodities and the cost to haul them is one of the determining factors as to whether the commodities are recovered or not. The cost of recovering the material is also considered. Furthermore, the model determines which is more efficient: a) to recycle paper for its fiber value, or b) to leave it in the waste stream for its Btu value if a heat recovery system is offered. The model will determine what percent of paper will be burned and what percent will be recycled as a function of market price for recycled paper fiber and its fluctuation versus the Btu value.

The most important question of cost is broken down into its different component parts alone, along with a total cost figure and a total cost per ton figure for the the whole plan. Costs may be divided into operating and maintenance costs, capital costs, finance costs, municipal costs, etc., or a summation of some of the different costs. The cost breakdown is given in constant dollars or inflated dollars. These costs (discounted or undiscounted) are also minimized by the model.

General Information

The discount rate is needed to give future costs in constant and meaningful dollar values. If a user is unsure of the discount rate, OMB figures should be used. OMB currently suggests a rate of 10 percent for consistency. The inflation rate is needed to determine future cost of inputs and the revenue from outputs; a differential rate of inflation for different commodities is also input. (See Cost Categories Discussion.)

Percentages by weight for the different elements in the waste stream should be given according to how much can be source separated and how much there is in total. If the particular element such as ferrous metal is to be separated in a process, that should be noted, and it should also be noted as to what percent of the waste stream will be ferrous metal that is recoverable. Residue is defined as anything that is not recoverable paper, glass, or metal.

Figures are generally available for Btu content of paper, but the Btu value of residue (as defined above) and MSW as a whole may vary from one area to the next.

The average price at the market for glass, paper, and metal is the price received if the commodity is delivered directly to the market, with the cost of haul figured separately. Average price means the expected price for that commodity in a known market, allowing for slight fluctuations of market. If there are large fluctuations of price due to recycling, it can be expected that source separation will cause a change in price given that price which factors in any expected change.

The cost of collection includes only the cost up to the point the truck is filled (or until the waste collected is hauled to be processed). The source point is the central point of a community which is considered the source of waste generated for that community for the purposes of measuring distances. The cost of collection can be considered the cost of getting the waste to that point from where it will be hauled to the waste processing facility.

The incremental cost of source separation is the cost in dollars per ton of pre-separated MSW. The cost of source separation includes the cost of source separation collection for paper, glass, and metal if all of these, then the incremental cost of source separation should only include the cost of the items being source separated. The type of source separation program to be used may affect cost significantly so it is important that the user choose a system of source separation before computing the cost. For any source separation program to be successful, the public must be educated. This added cost should be included in the incremental cost of source separation.

Sources are designated as belonging to one of three source separation categories:

1) No source separation

2) Routine source separation of paper, glass, and metal; or

3) Routine source separation with the separation of paper dependent upon the price of paper.

At sources in the third source category above - separation - paper is burned only if the price for paper on the paper market goes below a "trigger" price which is specified by the user. This trigger price system is described in detail in the Paper Market Discussion below.

The price-dependent variation of the amount of paper that is source separated produces a hidden cost of recycling paper which should be considered. While some paper may be recycled under the trigger price system, the capacity of the facility must be potentially capable of accommodating all of the paper waste.

A ratio may be specified which indicates the extent to which the costs of processing waste paper are generated by either actual or potential tonnage of paper processed. At the upper limit of 1.0, the ratio indicates that all of the cost of processing paper comes from the actual amount of paper processed. At the lower limit of 0.0, then the costs to the system arise from the maintenance of an unused potential for processing paper.

The cost of processing a ton of source separated paper is calculated as the cost of processing a ton of source separated paper in the same manner that a ton of MSW would be processed. This cost of processing separated paper will probably be lower than the cost of processing MSW for a number of reasons. Some of the factors causing this lower cost are: greater compactability, less water content, ease of handling, etc. A ratio, or percentage, can then be calculated. For example, if it costs $9.00 to process a ton of separated paper as waste and $10.00 to process a ton of MSW, then the ratio would be calculated as 9/10 - it costs 90 percent as much to process source separated paper as it does to process MSW.

This comparison between processing residue and mixed MSW is essentially the same as the comparison between source separated paper and MSW as described above. Of course, the ratio will probably be different. It might even be the case that the cost of processing residue will be larger than the cost of processing MSW. Each user will probably calculate a different cost for processing residue, depending on such factors as the composition of the residue, the components that have been source separated, and the effect of the source separation on the residue.

Source

Source refers to where MSW is generated. MSW is, in fact, generated by households, businesses, and industries. However, a source in the model is a conglomeration of these particular sources - usually a town, a city, or a country. The area that is being studied may be broken down into as many as sixty source regions.

To identify each region, give it a name such as "Region #1." An exact location of a source region should be given as a point in the geographic or population center of the area, that can be used for distance measurement purposes. This point is where all measurements are made from when considering the haul of MSW or source separated material to a processing facility or a market. Therefore, it may be convenient to consider as the source point a point such as a transfer station or the end of a collection route for a packer. The point chosen is considered, for the sake of the model, as the point where all collection (and thus collection costs) end, and where hauling (and thus all haul costs from the source) begin. The area being considered by the model may be broken into as many as 60 different sources, since that is the limit built into RRPlan. It is suggested, however, that the user not use more than 30 sources.

The tonnage of MSW generated within a region is derived either by multiplying population by per capita generation figures or from more accurate measures done by local sanitation authority.

The tonnage of MSW generated by a source region should be stated in daily or annual terms, rather than per collection. The amount collected per collection is of little use unless the frequency of collections is known, so that an annual, monthly, weekly, or daily tonnage figure can be calculated.

The source may be offered options regarding source separation: 1) source separation will not be done; 2) source separation will always be done for paper, glass, and cans; 3) source separation of paper will depend on the price of paper in the market place. If this option is chosen then paper will be burned for its Btu value instead of being recycled when the paper price goes below a "trigger" price which is specified by the user. This trigger price establishes a cut-off point above which paper is recycled and below which it is burned.

More than one trigger price may be used. The number of trigger prices must be entered on a source information page. A special section on the "Paper Market" is included below and discusses this system of trigger prices in more detail.

The cost of hauling source separated glass, paper, and metal is the cost per ton to haul these commodities to market. The most efficient means of transportation should be considered, e.g., truck, rail or barge. The cost should be calculated as the total cost per ton to deliver to market considering the location of the nearest market which can readily accept all of the glass, metal or paper which will be sent there. It is important to identify markets for each of the source separated materials, and have a market for each source since there may be a different market for different sources.

Cost Categories

Cost categories are RRPlan's method of accounting for different costs. Every input that has a cost or a revenue (a negative cost to a cost category) is associated with a cost category under which that cost is classified. The output summary of RRPlan reports all costs according to the different cost categories.

The user must have at least two categories; one should be operating cost and the other, capital costs. The user may define any additional cost categories he wishes but each must be designated as either a type of operating cost or a type of capital cost. The user may want to use separate categories to divide public vs. private costs or municipal costs vs. county or State costs. The way they are divided does not affect the solution or the summary of costs for the overall solution. The model does however print the solution in terms of the cost categories for the convenience of the user.

The user should assign a name and number to each category. The user should then determine whether the category is an operating or capital cost. Capital costs should be the costs of construction or of large equipment. Operating costs include all revenues from processes and everything not considered a capital cost. Maintenance costs, cost of administration, salaries, etc. would all be considered under operating cost.

For each type of category a differential inflation rate should be given. The differential inflation rate is the difference between the general inflation rate and the inflation rate for that particular category given as either positive (greater increase in prices), negative (a lower increase in prices, or a decrease) or zero (no difference from general inflation rate). This information is needed to determine future costs in constant dollars, and to give future current costs.

For capital cost categories, three additional questions must be answered: useful life of the category, years to capitalization, and the interest rate. The useful life of the category is the length of time that the asset, whose cost is represented by this category, will be useful to the owner for the purpose intended upon purchase. An example is an incinerator which is expected to last 15 years; if it is assumed that in 15 years it will have to be replaced, then the useful life is 15 years.

The number of years to capitalize is the number of years expected to pay off the loan, bond or whatever method was used to borrow the money. The years to capitalize may be the same as or different from the useful life. The fewer years of capitalization there are, the greater the per year cost, but interest cost will be less. If useful life is longer than capitalization, the last years of a facility will have very low costs compared to the years before that.

The interest rate is the expected interest rate on the loan to pay off this capital category. The interest rate may be a weighted average of two or more interest rates, since there may be two or more loans used in a capital cost category. Two different loans for one facility may be included in two different capital cost categories.

Commodities

A commodity is defined by the model as the inputs and outputs of processes. Commodities are the materials which are transported between all geographical locations; anything which is hauled must be defined as a commodity. Examples of input commodities are: mixed MSW hauled in a packer or source separated residue hauled in a trailer truck. Output commodities would be items such as: incinerated ferrous or steam. The commodities, just as the sources, are numbered consecutively. The first five commodities (numbered one through five) are determined by the model as:

1) mixed MSW hauled in a van (trailer truck);

2) mixed MSW hauled in a packer;

3) source separated paper hauled in a van;

4) source separated residue hauled in a packer; or

5) source separated residue hauled in a van.

These are all input commodities which are hauled from a source to a process. All other commodities will be defined by the users, most of these will be output commodities from a process to another process or to a market. For example, the commodity "MSW hauled in a Packer" may be the input at a particular process such as an incinerator. Three output commodities may be the result of the incineration process 1) "Steam", 2) "Incinerated Ferrous", 3) "Incineration Residue". These three commodities would be sent to three different places, two to markets and one would go to another process. "Steam" would be sold to a factor nearby, "Incinerated Ferrous" would be hauled to a market and sold as ferrous scrap, "Incineration Residue" would be hauled to a landfill process to be buried.

For each commodity the user must give the cost to haul that commodity. The cost of haul can be given in two ways, cost per ton mile, and cost per ton to haul between two locations.

The cost per ton mile will be the cost to haul a commodity anywhere within the region for some constant rate divided by tons and miles. If it cost $100 to haul ten tons of a commodity ten miles then the cost would be $1.00 per ton per mile. When the costs are given as per-ton-mile, the costs should be fairly consistent throughout the area for hauls from one location to another. Also when using the per-ton-mile haul cost method the user must specify the mode of transportation since the cost per-ton-mile will vary with the size and type of vehicle used. Some examples of specifying a mode of transport are the first five commodities defined by the model. They specify transport by a packer or a trailer van since the haul cost for MSW or residue will be different for each vehicle. Some examples of user defined commodities would be "ferrous metal in a rail car" or "glass cullet in a trailer truck." It is not necessary to specify the mode of transport if there is only one.

The cost of haul per ton between two locations is the cost in dollars per ton to haul from a source or site to a market or site. The mode of transport is considered to be the most efficient way of transporting the commodity between the two locations, the user need not specify the mode of transport. The user merely has to specify the source or site where the commodity is to be hauled and then give the cost per ton to haul between these two points. An example of this method is the following: the commodity "Incinerated Ferrous" will be hauled from "Incinerator A," a process site to a market, "Rusty's Recycled Metal." The most efficient method of transport is by rail to that market and the cost is $50 a ton. The user would therefore list the process site, the market it goes to and the cost $50 per ton to haul between those two points. If the commodity "Incinerated Ferrous" is being produced as an output at another incinerator called "Incinerator B" and that the commodity is being sold at "Daedlus' Scrap Metal and Wing Maker." Also, it is determined that the most efficient mode of transport is by truck and that the cost for the haul between these two locations, which are closer together than the two in the first example, is only $25. The user would list on the commodity sheet for "Incinerated Ferrous" the two new locations and the cost for haul between them.

The user must give haul costs for the first five commodities defined by the model unless they are not to be used, in which case the haul costs are set at zero. The user may define up to fifteen additional commodity categories. The other limitations on commodities are the following: all processes at a particular location must receive only one commodity as input; each process may output as many as seven commodities; each market may receive only one commodity.

Paper Market

Source separated paper does not go to a process. Therefore, market information for source separated paper should be entered separately from the other markets since it is treated differently than other markets. Paper can be either sold for its fiber or burned for its Btu value. The market for recycled paper determines whether paper is recycled or not.

A price frequency distribution is how often the price of paper fell within a certain interval of say \$10 - \$15. To draw up the distribution, define, for example, 3 intervals: \$5 - \$10, \$10 - \$15, \$15 - \$20, with \$5 being the lowest price of paper. If the price of paper for the last 2 years fell between \$5 and \$10 thirty percent of the time and in the other 2 intervals thirty-five percent of the time each, then that would be the price frequency distribution.

Sites and Processes

Process refers to a generic type of facility, such as a landfill, incinerator, transfer station, etc. used to process solid waste. Different operating and capital costs are associated with different size facilities. The user should define four different size facilities which are in general use, a minimum, two medium and a maximum sized facility. Capital and operating costs should then be given for each size. For example, the process waterwall incinerator may have sizes of 250, 500, 750, and 1000 tons per day, representing the smallest, intermediate, and largest WW incinerators. The operating and capital costs would be different for each size facility. These different costs are used to make a cost curve for operating cost and one for capital cost for each facility being considered. The curve will give us the costs of each facility for all the sizes within the intervals between four sizes defined by the user.

The user must always define the first process as a new transfer station which will be considered for all sources.

A site is the physical location where the processing of waste occurs. More than one process may occur at each site.

Location of Site

Location is the exact address, or physical location of the site. This is needed for the measurement of distances to and from the site.

Site Preparation Costs

These costs are those incurred when preparing the site for a facility. They include roads, fences, land developed where the facility would be, etc. They do not include the construction of the facility.

Process Revenues

Revenues which are realized within the facility as well as from the sales of certain process related outputs are process revenues. For example, if an incinerator produces steam to generate electricity to sell and also uses the steam to heat the facility, the savings in heating costs is considered a process revenue. For example, if steam could be used to generate electricity which was fed into the grid, it would not be necessary to define a separate commodity and market representing the sale of the electricity produced.

Years to Capitalization

This is the number of years to capitalize the loan used to have a facility at a site.

Remaining Useful Life

The number of years that the facility will remain functional at a particular site is the remaining useful life.

Interest Rate

Interest rate is the rate of interest being paid on the loan for a facility.

Landfill

If a landfill exists at the site (or is proposed) the information required about it is:

1) The acre-feet of space remaining which can be used.

2) The amount of land used per ton of input. (In acre-feet)

Input

There is an input associated with each process. This input is what is delivered to the facility to be processed. For a transfer station, the input would be MSW in a packer; for an incinerator the input could be MSW in a van, source separated residue, etc. Only one commodity may be input into each process.

Outputs

Outputs from each process are the commodities which result from processing. For each output, there is an output coefficient. This coefficient is the ratio of the output from the process to the input to the process. For example, incinerated ferrous is an output of incineration; then the output coefficient is equal ratio to the incinerated ferrous in tons resulting from the incineration; of a given number of tons of MSW input. For each output, there must be an output coefficient. There may be as many as two outputs from a process.

Market

A market is a place where an output of a process, a commodity, is sold. An example of a commodity would be steam, which would be output from an incinerator; the incinerator is a process. The market would be, perhaps a factory located near the incinerator. The firm that owns the factory is the name of the market. The address is the exact location of the market.

A market is unlimited if the market will accept any amount of the commodity which is produced; a limited market will only buy a certain amount of a commodity. A limited market is often a declining price market. A declining price market is one where the price per unit falls as the number of units increases toward the limit of the market. For any market with a declining price, such as steam, a price schedule should be provided which describes the decreasing price.

A fixed price market is one where the price is the same regardless of the level of output. The price may be fixed even though the market is limited. In this case, the price would be the same even as the output of the commodity reached the market limit.

A commodity may be produced for more than one market. A market that receives more than one commodity must have a questionnaire filled out for each commodity that the market receives. An example would be a company that accepts both steam and residue from a process.

A user needs to explain all sites from which the commodity is coming to that market. For example, if the market is for incinerated ferrous, then specify all sites that are offered incinerators as a process and might therefore sell ferrous to that market.

Capacity Limit

The capacity limit is the absolute maximum amount of input which can be processed in a year by a facility at a specific site. This does not have to be at the end of an interval, but can be within it. The number should be in kilotons per year.

Energy Options

If the user wants to use one of the two energy modes in RRPlan, either maximize net energy or optimize a linear combination of cost and energy, he must input energy requirement information. The easiest way of collecting the required data is to collect the information along with the cost information. Every activity that requires a dollar cost will probably require an energy expenditure.

For example, all haul cost information, collection, and source separation require an energy cost. All energy costs should be in millions of Btu's. Aside from explicit activities in the model there are energy savings from recycling paper, glass and metal, since the recycling process uses less energy. The savings in energy should be noted for each of these.

As for steam or heat energy released during processing, an energy value in millions of Btu's should be provided for each process showing the energy which is recovered from the waste stream.

Complete details can be found in Publication List 96 and 98.

APPENDIX XIII. TENTATIVE AGREEMENT FOR JOINT RESEARCH JAPAN--UNITED STATES

(Period December 1981 to October 1982)

Both sides agree to pursue Item (1) proposed by Japan and Item (2) proposed by U.S. to fullest extent possible:

(1) Gasification of Refuse Derived Fuel (Ebara Corporation)

AIST has been carrying out R&D involving dual fluidized bed gasification of the organic (plastic rich) portion of municipal refuse by operating a pilot plant at Yokohama, Kanagawa Prefecture, since 1973. The entire task has been carried out by Ebara Corporation under contract. This research is scheduled to be completed by the end of FY 1982 (March 31, 1982).

The U.S. is currently producing RDF from municipal refuse for possible use as substitute or supplemental fuel. If RDF could be converted into high quality gas in an efficient and economical manner, some beneficial application might be found, e.g., better market opportunities for waste-to-energy applications. Additionally, unwanted substances which are emitted by RDF in the course of its incineration may possibly be eliminated by gasification of RDF. It may be worthwhile to analyze the compositions of gas and other substances produced by the pyrolysis.

The experiment can be carried out at the said pilot gasifier in Yokohama. A specified amount (20 to 100 U.S. tons) of RDF will be transmitted to Japan for this purpose upon request of Japanese side. Data will be analyzed both in Japan and the U.S.

(2) Econometric models describing the market potential for various forms of recycled materials and energy from waste have been developed in the U.S. These models provide a basis for selecting the optimum resource recovery strategy for a region in terms of:

- o Markets available for the products
- o Technology selection
- o Size of plant
- o Transportation network
- o Refuse supply
- o Costs and revenues over the lifetime of the project

The data required for carrying out this analysis include:

- Specifications for the products to be sold, e.g., heat value, residues produced, pollution properties, quantity produced per input ton of refuse
- Size of plant
- Efficiency of plant
- Requirement of plant for energy and other operating costs
- Requirement of plant for labor
- Capital cost of plant
- Lifetime of plant
- Required treatment, if any, of input refuse
- Type and amount of emissions and residues from plant

The U.S. undertakes to carry out market potential studies in several areas of the United States for any and all sets of data provided by Japan. Mutual benefits will be:

- Japan learns if the processes and products being produced can be marketed in the U.S. profitably.
- Japan learns direction for further research to improve processes and products in terms of marketability in the U.S.
- U.S. learns whether Japanese technology can aid in dealing with solid waste management problems in various regions of the United States.

Both sides agree to further consider the attached lists of possible research items for possible action at a later time.

PROPOSED BY JAPAN

Possible Joint Research Items

(Jap. Gov. Institutes)

1. Combustion Studies of RDF or Other Solid Fuels

   (Gov. Ind. Dev. Lab., Hokkaido, AIST)

   There is a 25 cm square fluidized bed combustion reactor now under test operation. Utilization of combustion heat by heat exchange is studied here.

   In response to the U.S. proposal (3), physicochemical phenomena of combustion can be studied and some thermokinetic data may be obtained. RDF, coal, and other organic waste, or their mixtures can be burnt in the reactor and emissions such as HCl, NH_3, CO, CO_2, and hydrocarbons can be monitored.

2. Utilization of Ash Residues from an Incineration Plant

   (National Chem. Lab. for Ind., AIST)

   Treatment of ash residues from an incineration plant of municipal refuse is an important issue from the view point of reducing the environmental burdens and economically sound methods to reuse such ashes need to be found. Research involves effective classification of constituents in the ashes and utilization process development on reclaimed substances as well as effective design of the incineration system.

3. Acid Hydrolysis of Cellulose Materials

   (The same lab. as the above.)

   It is necessary to find the most economical process which would convert waste or low cost biomass into ethanol. Enzymatic or acid hydrolysis process is first required to convert the cellulose fraction of raw material into glucose.

   A two-stage batch reactor of acid hydrolysis originally designed is going to be examined.

PROPOSED BY UNITED STATES

Possible Joint Research Projects

1. Dusts created by the electric furnace process for the production of steel contain valuable metal units. Economically sound methods to recycle such dusts on furnace-by-furnace basis need to be found. Research involves particle identification, classification and design of a system to separate out desired constituents.

2. Mill scales and sludges created by rolling processes in the steel industry need to be doiled for reclamation of metal units. Research involves characterization of such wastes and means to reclaim oils and/or energy plus metal units. Thermal and chemical processes need to be compared.

3. Combustion products created by burning refuse or mixtures of fossil fuels and refuse derived fuels need to be studied in order to prevent unwanted emissions, e.g., dioxin, and to provide for most efficient firing characteristics. Research involves setting up on-line monitoring for unwanted emissions and determination of basic thermokinetic data on the firing process. For example, co-firing of coal with refuse derived fuel reduces SO emissions drastically. The mechanism for this process should be deduced in order to optimize use of coal RDF mixtures for power boilers.

4. More economical means of recycling plastics from mixed wastes are needed. The Japanese are ahead of U.S. on the technology to do so. Joint research on new uses for waste plastics could be beneficial to the U.S.

5. The corrosion propensities of refuse and various forms of refuse derived fuels need to be studied. Joint research could aid in assuring that the potential for downtime or even failure of very expensive capital equipment is minimized.

Contact for Japan: S. Suzuki
AIST

Contact for U.S. : H. Yakowitz
NBS

APPENDIX XIII. GASIFICATION OF REFUSE DERIVED FUEL IN A PAIRED FLUIDIZED BED PYROLYSIS UNIT

Results developed as part of the scientific exchange
program of the respective governments of Japan and the United States

Prepared cooperatively by the Agency of Industrial Science and Technology,
Ministry of International Trade and Industry, Government of Japan,
Ebara Corporation, Japan (acting for the Government of Japan),
and the National Bureau of Standards

Text prepared under the direction of Mr. S. Suzuki (AIST)
Text edited by Dr. Harvey Yakowitz (NBS)

Foreword

As part of the scientific interchange program initiated by the United States Government and the Government of Japan, the Department of Commerce was selected by the White House to be the pilot agency for a project concerned with resource recovery from discards originally destined for waste. Such discards include municipal waste and industrial waste. Under terms of the agreement signed by the President and the Prime Minister on May 2, 1980, the United States and Japan will exchange small teams of government scientists in order to examine resource recovery in the respective countries and to formulate possible joint research ventures.

The Office of Recycled Materials of the National Bureau of Standards (NBS/ORM), which was charged with fulfilling the duties assigned to the Secretary of Commerce by Subtitle E of the Resource Conservation and Recovery Act as ammended (P.L. 94-580; PL 96-482) was designated as the U.S. contact point for this project. The Japanese team visited the U.S. in December, 1981; NBS/ORM arranged the itinerary and provided technical briefings and an overview of resource recovery activities. At that time, NBS/ORM and Japanese representatives concluded an agreement for joint research to be performed as part of the project. The text is as follows:

AGREEMENT FOR JOINT RESEARCH JAPAN-UNITED STATES

Both sides agree to pursue item (1) proposed by Japan and item (2) proposed by U.S. to fullest extent possible:

(1) Gasification of Refuse Derived Fuel, RDF (Ebara Corporation)

AIST has been carrying out R&D involving dual fluidized bed gasification of the organic (plastic rich) portion of municipal refuse by operating a pilot plant at Yokohama, Kanagawa Prefecture, since 1973. The entire task has been carried out by Ebara Corporation under contract. This research is scheduled to be completed by the end of FY 1982 (March 31, 1982).

The U.S. is currently producing RDF from municipal refuse for possible use as substitute or supplemental fuel. If RDF could be converted into high quality gas in an efficient and economical manner, some beneficial application might be found, e.g., better market opportunities for waste-to-energy applications. Additionally, unwanted substances which are emitted by RDF in the course of its incineration may possibly be eliminated by gasification of RDF. It may be worthwhile to analyze the compositions of gas and other substances produced by the pyrolysis.

The experiment can be carried out at the said pilot gasifier in Yokohama. A specified amount (20 to 100 U.S. tons) of RDF will be transmitted to Japan for this purpose upon request of Japanese side. Data will be analyzed both in Japan and the U.S.

(2) Econometric models describing the market potential for various forms of recycled materials and energy from waste have been developed in the U.S. These models provide a basis for selecting the optimum resource recovery strategy for a region in terms of:

- Markets available for the products
- Technology selection
- Size of plant
- Transportation network
- Refuse supply
- Costs and revenues over the lifetime of the project

The data required for carrying out this analysis include:

- Specifications for the products to be sold, e.g., heat value, residues produced, pollution properties, quantity produced per input ton of refuse
- Size of plant
- Efficiency of plant
- Requirement of plant for energy and other operating costs
- Requirement of plant for labor
- Capital cost of plant
- Lifetime of plant
- Required treatment, if any, of input refuse
- Type and amount of emissions and residues from plant

The U.S. undertakes to carry out market potential studies in several areas of the United States for any and all sets of data provided by Japan. Mutual benefits will be:

- Japan learns if the processes and products being produced can be marketed in the U.S. profitably.
- Japan learns direction for further research to improve processes and products in terms of marketability in the U.S.
- U.S. learns whether Japanese technology can aid in dealing with solid waste management problems in various regions of the United States.

Both sides agree to further consider the attached lists of possible research items for possible action at a later time.

PROPOSED BY JAPAN

Possible Joint Research Items
(Japanese Government Institutes)

1. Combustion Studies of RDF or Other Solid Fuels (Government Industrial Development Laboratory, Hokkaido, AIST).

There is a 25 cm square fluidized bed combustion reactor now under test operation. Utilization of combustion heat by heat exchange is studied here.

In response to the U.S. proposal (3) (see overleaf) physicochemical phenomena of combustion can be studied and some thermokinetic data may be obtained. RDF, coal, and other organic waste, or their mixtures can be burned in the reactor and emissions such as HCl, NH_3, CO, CO_2, and hydrocarbons can be monitored.

2. Utilization of Ash Residues from an Incineration Plant (National Chemistry Laboratory for Industry, AIST).

Treatment of ash residues from an incineration plant of municipal refuse is an important issue from the viewpoint of reducing the environmental burdens, and economically sound methods to reuse such ashes need to be found. Research involves effective classification of constituents in the ashes and utilization process development on reclaimed substances as well as effective design of the incineration system.

3. Acid Hydrolysis of Cellulose Materials (The same Laboratory as 2. above.)

It is necessary to find the most economical process which would convert waste or low cost biomass into ethanol. Enzymatic or acid hydrolysis process is first required to convert the cellulose fraction of raw material into glucose.

A two-stage batch reactor of acid hydrolysis originally designed is going to be examined.

PROPOSED BY UNITED STATES

Possible Joint Research Projects

1. Dusts created by the electric furnace process for the productionof steel contain valuable metal units. Economically sound methods to recycle such dusts on furnace-by-furnace basis need to be found. Research involves particle identification, classification and design of a system to separate out desired constituents.

2. Mill scales and sludges created by rolling processes in the steel industry need to be doiled for reclamation of metal units. Research involves characterization of such wastes and means to reclaim oils and/or energy plus metal units. Thermal and chemical processes need to be compared.

3. Combustion products created by burning refuse or mixtures of fossil fuels and refuse derived fuels need to be studied in order to prevent unwanted emissions, e.g., dioxin, and to provide for most efficient firing characteristics. Research involves setting up on-line monitoring for unwanted emissions and determination of basic thermokinetic data on the firing process. For example, co-firing of coal with refuse derived fuel reduces SO_x emissions drastically. The mechanism for this process should be deduced in order to optimize use of coal RDF mixtures for power boilers.

4. More economical means of recycling plastics from mixed wastes are needed. The Japanese are ahead of U.S. on the technology to do so. Joint research on new uses for waste plastics could be beneficial to the U.S.

5. The corrosion propensities of refuse and various forms of refuse derived fuels need to be studied. Joint research could aid in assuring that the potential for downtime or even failure of very expensive capital equipment is minimized.

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NBS

NBS/ORM arranged to ship to Japan about 35 tons of fluff RDF produced at the Baltimore County, MD resource recovery facility. This material arrived in Japan in early November, 1982.

In accord with the foregoing agreement, this RDF was gasified in a pilot scale resource recovery plant in Yokohama. The results of this gasification experiment are described in this NBS Special Publication. The text, as received from the Agency of Industrial Science and Technology of the Japanese Ministry of International Trade and Industry, was edited by Dr. Harvey Yakowitz, Chief, NBS/ORM.

Special thanks are given to the Text-Editing Facility of the National Measurement Laboratory of NBS for preparation of the final version of the report.

Abstract

The refuse derived fuel (RDF) produced at the Baltimore County Resource Recovery Plant and provided by NBS to the Government of Japan was gasified in a paired-bed pyrolysis unit, i.e., a fluidizing medium (sand) was circulated between a pyrolysis reactor and a combustion reactor. Thus, pyrolysis and combustion occur separate from one another; hence, the name "paired-bed."

The gas refining equipment consists of two chains, one for pyrolysis gas and the other combustion exhaust gas:

1. A cyclone separates char from the gas coming from the pyrolysis pyrolysis reactor. This char is fed to the combustion reactor for burning. After the gas passes through a heat exchanger and is quenched in a carbon deposit protector, a tar-separator removes oil mist and the gas is cleaned in a scrubber. A small portion of this clean gas is pressurized by a blower, preheated in a heat exchanger and used to fluidize the pyrolysis reactor bed; the remaining gas is sent to a tank for storage.

2. The exhaust gas generated by the combustion reactor is discharged into the atmosphere after being treated by means of a two-stage cyclone and electric dust precipitator. The non-combustible substances contained in the feed stock are discharged from the bottom of the combustion tower periodically.

The RDF was fed into the system at a rate of 0.6 to 1.0 tonnes per hour. The pyrolysis reaction temperature was about 650 °C. The following ultimate analyses were performed: (N.B. "T" is "Trace")

1. Feedstock
   a. Main components
      C, H, N, Cl, Na, K, Ca, Ash.
   b. Harmful components
      Cu, Pb, Cd, T-Hg, As, T-Cr, Al.
   c. Heat value
2. Pyrolysis gas components
   a. Main components
      H_2, O_2, N_2, CH_4, CO, CO_2, CmHn.
   b. Harmful gas components
      HCl, H_2S, NH_4, HCN, SO_x, NO_x.
   c. Heat value

3. Flue gas

   a. Main gas components

      O_2, N_2, CO, CO_2.

   b. Harmful components
      SO_x, NO_x, HCl, dust.

4. Ash

   a. Main components
      C, H, N, S, Cl, Na, K, Ca.

   b. Heavy metals
      Cu, Pb, Cd, T-Hg, As, T-Cr, Al, etc.

5. Waste water

   a. Main components
      pH, EOD, COD, SS, n-Hex, Phenol, NH_4^+, Cl^-, CN^-, etc.

Results of the experiment include descriptions of:

- Heat and material balance.
- Gas and energy recovery rate.
- Evaluation of the data from public nuisance standpoint.
- Cost estimation.
- Final economics.

From these results, the total process flowsheet for a commerical plant, including pretreatment system was deduced. Thus, the final output allows assessment of the commercial feasibility of the paired fluidized bed pyrolysis unit under pilot plant conditions.

Key Words: Baltimore County (MD) Resource Recovery Facility, Cooperative Research (Japan-U.S.), pilot plant scale-up for resource recovery from waste destined for disposal, pyrolysis of refuse derived fuel, refuse derived fuel gasification, solid waste management, waste-to-energy systems.

Gasification of Refuse Derived Fuel in a Paired Fluidized Bed Pyrulysis Unit

Report Completed

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Ministry of International Trade and Industry,

Government of Japan

In cooperation with Ebara Corporation, Japan

This work described in this report and the gasification experiment were carried out in response to the--Tentative Agreement for Joint Research Japan-United States, December, 1981.

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1. Background

The Agency of Industrial Science and Technology (AIST) in the Japanese Ministry of International Trade and Industry (MITI) has been a strong advocate of the National Resource Recovery System R&D program since its inception in 1972. In 1978, as the final phase of this program the pilot scale plant "Stardust '80" was constructed in Yokohama. Since 1979, many demonstration operations including several periods of long-term operation, mostly using municipal solid wastes from Yokohama as input material, have been performed successfully.

The goal of the program was to develop and demonstrate resource recovery methods and equipment which would represent best possible technology for pollution control, safety and maintenance, which would also allow for economically efficient recovery of resources. This goal has been largely achieved; the technology which has been developed is now ready for commercialization.

Nevertheless, the location and profitable exploitation of suitable markets for the recovered resources is the next challenge which must be dealt with satisfactorily. The viability of a resource recovery system is largely dependent upon market capacity and selling price of the recovered resources. Thus, part two of the tentative agreement for joint research, Japan--United States (December, 1981) calls for the application of National Bureau of Standards resource recovery marketing and planning models.

2. Introduction

(1) Outline of Stardust '80 Yokohama Plant

"Stardust '80 (Yokohama Plant) was operated in the fiscal year 1979-1980[1] as a materials recovery prototype system meant to recycle such useful resources as compost, pulp, fuel gas and light-weight aggregates from municipal refuse. (Material Recovery System -MRS- operation). Since April, 1981, energy recovery systems have been in operation--in both Yokohama and Tokyo--to recover methane gas and fuel oil. (Energy Recovery System--ERS--operation).

Fact Summary for Two-Bed Pyrolysis Gasifier
of Stardust '80 Yokohama Plant:

Opening:	May 1979
Principals:	Agency of Industrial Science and Technology M I T I (Owner) Designer and Operator: Ebara Corp.
Volume:	Design and actual; 24,000 kg per day in three shifts

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[1] The fiscal year in Japan begins on April 1.

Technology:	Pyrolizer, dust collector, heat exchanger, gas refiner and waste water treatment plant.
Products:	Fuel, gas, electricity and steam.
Cost:	$3 Million (1978 basis).

(2) Process flow of pyrolysis system

The pyrolysis gasification system consists of a pyrolysis reactor and combustion reactor. A fluidizing medium (sand) is circulated between two towers; the system is designed to perform pyrolysis and combustion separately, for which reason it is called "Two-Bed Type Pyrolysis."

Figure 1 shows the process flow. The input stock material is fed into the pyrolysis reactor, and the fuel gas generated by pyrolysis reaction is sent into the gas holding chamber after undergoing char-separating, heat-exchanging and gas cleaning processes. A portion of the resulting gas is recycled to the reactor for utilization as fluidizer gas.

Meanwhile, the char (carbonized substances) generated in the reactor is sent together with the sand to the combustion reactor, where air is blown in to aid combustion. The remaining char, which accompanies the pyrolysis gas, is intercepted and separated by means of a two-stage cyclone. The material is also burned in the combustion reactor, where its energy contribution is utilized as a source of heat. The resultant energy generated by combustion is transferred to the sand, which is then recycled to the pyrolysis reactor.

The pyrolysis gas passing through the heat exchanger is cleansed of oil, precipitated carbon bearing particles and noxious gases by means of a spray tower and a scrubber. The scrubbing water is sent to the waste water treatment unit where, after removal of harmful substances, it is discharged into the local sewer system. All of these operations are controlled by means of a centralized system.

The exhaust gas generated by the combustion reactor is discharged into the atmosphere after being treated by means of a two-stage cyclone and an electrostatic precipitator. The noncombustible substances contained in the input stock material are discharged from the bottom of the combustion reactor periodically.

Features of Main Equipment Components

(i) Stock Material Feeder

The RDF is sent to the input stock material feeder (screw type) from the storage silo by means of a constant rate feed mechanism: the stock material feeder is of the solid-overflow type so that the stock material usually can be kept at a constant level. No bridging problems have been encountered to date with this system.

The feeder unit has two-stages with a taper-type feeder followed by a straight-type feeder which prevents gas leakage and also prevents the stock material from being cracked at a low temperature. Therefore, even plastics, which previously were difficult to introduce properly, can be inserted very smoothly and at a constant rate.

(ii) Reactor Body

The pyrolysis reactor and the combustion reactor are connected by two pipes, which allows the fluidizer sand to circulate between the two reactors. The temperature of the fluidizer sand, which has undergone some reduction due to the endothermic thermal cracking reaction occuring in the pyrolysis reactor, is sent to the sand ejector together with whatever char is simultaneously formed. This char reacts with the air stream introduced to blow the sand up to the combustion reactor for burning; thus, the temperature of the sand is raised. This hot sand is circulated back into the pyrolysis reactor.

The sand circulation rate can be controlled satisfactorily by merely injecting a small amount of air into the ejector section. During operation, sand circulation rates ranging from 20 to 30 tonnes per hour have been maintained. In addition, the difference in temperature between the upper and lower parts of the fluidized bed can be stabilized to within ±2 °C, thus providing for a very stable thermal field. The resultant pyrolysis gas has exhibited high uniformity with few fluctuations in composition.

Incombustibles in the input stock material can be easily separated and discharged by means of the air classifier stream. The small amount of sand which is discharged along with these incombustibles can be reintroduced into the combustion reactor after the separation is accomplished.

(3) Experiment

An RDF gasification experiment was performed under the following conditions;

Place:	Two-Bed Pyrolysis Gasification Subsystem in Stardust '80, Yokohama Plant. (Yokohama City, Kanagawa Prefecture)
Time:	November 9-11, 1982
Stock material:	RDF (fluff) - 33.5 metric tons. Produced in Baltimore County's Resource Recovery Facility, in Maryland, U.S.A. This material was provided through the National Bureau of Standards. The entire amount was disposed via gasification during the above mentioned three-day period.

(4) Schedule

On October 28, 1982, 33.5 tonnes of RDF were received and placed in the storage pit of the Stardust 80 resource recovery pilot plant. This RDF was confirmed to be in good condition (no fermentation), despite the long transit time between the U.S. and Japan.

A pyrolysis gasification experiment was carried out for three days as follows:

November 8	Heat-up operation of reactor bodies
9-11	Pyrolysis gasification experiment
11	Blow-down operation

(5) Operating conditions

Table 1 lists important operating parameters for this experiment.

Table 1

RDF feed rate	700 - 1200 kg/hr
Pyrolysis reaction temperature	640 - 680 °C[a]
Combustion reactor temperature	700 - 740 °C
Both reactors maximum pressure	600 - 1000 mmAq-gauge
Fluidizer sand circulation rate	25 - 30 tonnes 1 hr

[a] This range has been found to include the most suitable temperature for recovering energy from refuse.

3. Experimental Results

(1) Properties of products and residues

(a) Pyrolysis product gas

Table 3 lists the concentration of the pyrolysis gas recovered in this experiment, and figure 2 shows the relation between pyrolysis reaction temperature and gas composition produced from RDF.

The maximum calorific value of the pyrolysis gas from the U.S. RDF was equal to the that of the gas produced by the MSW of Yokohama City. Pyrolysis gas yield is about 0.5 Nm^3/kg-dry RDF in the temperature range 650 °C to 670 °C; higher temeratures yield more H_2, CO and CH_4 rich gas and less CO_2 rich gas.

The pyrolysis gas contains several potentially harmful gases. Table 4 shows the concentrations of such gases before and after scrubbing of the pyrolysis gas. These potentially harmful gases can be minimized by alkali cleaning and water cleaning. The product gas can then be used in power plants and other industrial applications where medium BTU clean fuel gas would be economically advantageous.

(b) Exhaust gas

Table 5 lists the components and concentrations of the combustion reactor exhaust gas along with the values specified as standards for incinerator exhaust gas in Japan. The concentrations of the potentially harmful gases without gas cleaning and without additives for the elimination of HCl are lower than the incinerator exhaust standard values. Moreover, the results confirm that the present system contains intrinsic low-NOx-producing capabilities. This capability occurs, in our view, because the temperature of the combustion reactor is lower than that of conventional incinceration systems.

Therefore, water was added to the RDF in order to increase its bulk density, and the RDF moisture content was thus raised to 35%.

With regard to HCl gas concentration, satisfactorily low levels were maintained without adding the HCl gas absorbent $Ca(OH)_2$. Amounts of heavy metals are also satisfactorily low. Most of the heavy metals in the RDF reported to the ash.

(c) Ash

Tables 6 and 7 respectively list the ash components and extraction procedure test results for the ash collected by the cyclone and the electrostatic precipitator. Since the content of heavy metals in the Baltimore County RDF is low, most of the heavy metals reported to the ash. Each of the heavy metal values as determined in this experiment satisfies Japanese Government mandatory requirements.

The ash ignition loss in weight is 1.9%; no unburned residue could be found in the incombustibles discharged from both reactors.

(b) Waste Water

Table 8 lists the properties of raw and treated waste water resulting from this experiment. The waste water treatment system employs various physical-chemical treatments such as oil/water separation, solid/liquid separation, stripping, filtration, activated carbon adsorption, etc. The raw waste water has some organic contaminants (see BOD and COD) that exceed 1 percent, but the concentrations of the heavy metals fully satisfy the standards for Japan even in the raw waste water.

As a result, the treated water easily satisfies the requirements set forth in the Kanagawa Prefecture Sewage Ordinance. This water was therefore discharged to the local sewer system.

Table 2 lists the composition of the RDF provided for use in this experiment:

Table 2. Composition of RDF

			R D F
Moisture content[a]		%	14 ~ 20
Bulk density		t/m^3	0.07 ~ 0.09
Calorific value		Kcal/Kg	4650 (gross); 8370 BTU/lb 3690 (net); 6640 BTU/lb
Ultimate analysis	C		38.6%
	H		5.7%
	O		44.7%
	N		0.8%
	S		0.17%
	Cl		0.23%
	Ash		9.8%
Composition	Paper		66.7%
	Textile		21.3%
	Plastics		9.3%
	Yard waste		2.2%
	Metals		0.5%
	Glass		0%
	Garbage		0%

[a] An inclined vibration conveyor, which is incorporated in the refuse transfer line which was intended to carry the RDF from the storage pit to the gasification site refuse silo, could not be used to transfer the RDF (bulk density: 80hg/m^3) because this conveyor is designed to deal with much heavier refuse (bulk density: around 250hg/m^3).

Table 3. Properties of pyrolysis product gas

Component		concentration (%)
H_2		15.3 ∼ 16.2
N_2		1.9 ∼ 3.9
CH_4		12.9 ∼ 16.2
CO		32.0 ∼ 34.6
CO_2		17.5 ∼ 22.9
C_2H_4		4.5 ∼ 6.0
C_2H_6		2.8 ∼ 3.0
C_3 - Hydrocarbons		3.3 ∼ 3.7
C_4 - Hydrocarbons		1.3 ∼ 2.0
Calorific value	kcal $_{Nm^3}$	5450 ∼ 5850* (gross) 5020∼5400** (net)

* 610--655 Btu/ft^3
** 560--605 Btu/ft^3

Table 4. Potentially harmful gas phase constituents in product gas

Components	Before scrubbing	After scrubbing
H_2S	520	150
SO_x	230	<10
HCN	711	14
NH_3	142	<10
HCl	790	16
NO_x	Not detected	Not detected

unit: ppm

Table 5. Properties of exhaust gas

		Concentration	Incinerator exhaust standard value
	O^2	7.5%	
Main gas	N^2	81.4%	
	CO^2	11.1%	
	HCl	152 ppm	<430
Harmful gas	NOx	76 ppm	<250
	SOx	<10 ppm	<300[a]
	Soot dust	0.06 g/Nm^3	<0.1
	Cd	<0.01 mg/Nm^3	<0.5[b]
Heavy Metals etc.	Pb	0.37 mg/Nm^3	<10[b]
	Cu	0.15 mg/Nm^3	
	T-Cr	0.02 mg/Nm^3	
	T-Hg	<0.01 mg/Nm^3	
	As	<0.01 mg/Nm^3	

[a] Stipulated K value (K = 1.17).

[b] General smoke emission standard values.

Table 6. Ash components

Components	Concentration (%)	Components	Concentration (%)	Components	Concentration (ppm)
C	1.1	Na	2.3	Cu	840
H	<0.3	K	1.1	Pb	84
N	<0.3	Ca	0.32	Cd	6
S	<0.03	Al	5.9	T-Hg	0.01
Cl	0.28	Ignition loss in weight	1.9	T-Cr	120
				As	2.9

Table 7. Extraction procedure test value of ash

	Concentration	Standard value
Cd	<0.01	<0.3
Pb	<0.1	<3
As	<0.05	<1.5
Cr^{6+}	<0.05	<1.5
T-Hg	<0.0005	<0.005
R-Hg	Not detected	Not detected
Org-P	<0.01	<1
PCB	<0.0005	<0.003
CN-	<0.1	<1

unit: mg/1

Standard values for landfilling in Japan.

Table 8. Properties of raw and treated waste water

	Raw waste water	Treated waste water	Standard[a] value
pH	8.0	7.3	5.7 ~ 8.7
BOD [mg/ℓ]	18,000	50	<300
COD "	14,000	90	----
Suspended Solids	690	19	<300
Phenols "	1,100	<0.05	<0.5
Cd "	0.03	<0.01	<0.1
CN- "	20	<0.1	<1
Pb "	0.1	<0.1	<1
T-Hg "	0.0006	0.0005	<0.005
Cu "	<0.1	<0.1	<1
T-Cr "	<0.05	<0.05	<2
n-Hexane "	230	<5	<5
NH_4^+ "	340	136	----
Cl "	1,200	900	----

[a] Requirements set forth in Kanagawa Prefecture Sewage Ordinance.

(2) Mass and heat balances

Figures 3 and 4 illustrate the mass and heat balance relationships obtained in this experiment. As shown in figure 3, 317 Nm of medium BTU fuel gas was produced from 1139 kg (moisture content 35 percent) of RDF in one hour. The gross calorific value ranges from 5450 ~ 5850 Kcal/Nm^3 in the pyrolysis reaction temperature range of 640 ~ 680 °C. The experimental results indicated that 191 Nm^3 fuel gas and 280 kg (6 kgf/m^2) steam could be recovered as products which could in turn be supplied to some external location.

Details concerning mass and heat balance can be outlines as follows:

Gasification rate[1]	51.3 % (Kcal-gas/Kcal-RDF)
Gas energy recovery rate	30.5 % (Kcal-gas/Kcal-RDF)
Total energy recovery rate[2]	36.2 % (Kcal-gas.steam/Kcal-RDF)

[1] Gasification rate = $\frac{\text{calories of dry product gas}}{\text{calories of dry RDF}}$

[2] Total energy recovery rate = $\frac{\text{total recovered calories of gas and steam}}{\text{total colories of RDF}}$

Experimental factors affecting the observed energy recovery include the following as there were virtually no incombustibles in the RDF:

(i) operations meant to separate and discharge the incombustibles from the pyrolysis reactor were not necessary and

(ii) discharging the high temperature fluidizer sand (including some incombustibles) from the combustion reactor was also unnecessary. Therefore, typical input energy requirements for the reactor were reduced and a significant amount of auxiliary fuel gas (product gas) was thereby saved.

To correct the results of the energy recovery rate computed for typical input RDF with a 15 percent moisture content (as mentioned before, moisture was increased to around 35 percent by the need to add water to the RDF) we used the following values: Gas energy recovery rate 38.1 percent (Kcal-gas/Kcal-RDF); Total energy recovery rate 43.8 percent (Kcal-gas.steam/Kcal-RDF).

(3) Utilities

Table 9 lists the operating costs of this gasification experiment.

Since the pilot plant was designed for the purpose of research and development with respect to gasification technology:

1. Some equipment in the system, such as compressors and blowers, has built-in excess capacity meant to cope with unusual experimental conditions, e.g., aimed at the determination of the upper limits of the system's operational capabilities.

2. In the waste water treatment system, physical-chemical treatment facilities had to be employed instead of less costly biological methods because of the long shutdown intervals occasioned by the irregular testing schedule for Stardust 80. (With biological treatment systems, it is difficult to maintain the function properly while the system is not in operation).

The right hand column of table 9 therefore shows our estimate of operating costs corrected to conform to optimal conditions.

Table 9. Utilities and operating costs

	Consumption per hour	Cost in yen per refuse ton	Corrected cost in yen per refuse ton
Electricity	340 kWH	5,236	2,510[a]
Water	4 m^3	1,080	1,080
Town gas[b]	2 Nm^3	316	316
Nitrogen gas	0.7Nm^3	210	210
Sand	15 kg	150	150
Chemicals for boiler	1 kg	800	800
25 % NaOH	9.4 kg	348	348
35 % H_zSO_4	6.5 kg	410	410
1 % coagulant	6.1 kg	134	134
Activated carbon	30 kg	9,750	270[c]
$Ca(OH)_z$	0 kg	-----	-----
Nourishing salinity	0 kg	-----	20
Total	-----	18,434	6,348

[a] Since 52% of the electricity can be generated by a gas engine (see description below) using recovered fuel gas, the purchase of only 163 kwh of electricity is needed.

[b] Town gas is used for the pilot flame of the auxiliary burner.

[c] With the physical--chemical treatment large amounts of activated carbon are consumed, but in the case of the biological treatemnt, almost all of them are saved.

Gas engine generator

Since 1980, the gas engine generator has been operated for more than 1,000 hours using over 70,000 Nm^3 of recovered fuel gas. We have confirmed that the gas recovered was sufficiently clean and high in calorific value to use for the gas engine, and that the efficiency of energy conversion was as high as 35%. The gas engine employed in the Stardust '80 Plant is a slightly modified standard diesel engine, the main specifications for this engine are as follows:

Type	4 cycle, water cooled, vertical type
Cylinders	6--150 X 165
Generating power	300/1800 PS/RPM 200 kw

4. Implications of scale-up to commercial plant size

(1) Process and scale

In this section, computations describing the expected characteristics of a commercial-scale plant based on the Stardust '80 resource recovery system are discussed.

Calculations for the following two cases were performed by means of a modified computer program which was developed on the basis of the previously described gasification experiment.

Case 1: Pyrolysis gasification plant (including gas engine generator) stock material: RDF 1000 tonnes/day (produced in the U.S.). In this case, RDF is gasified with the same process as that of the Stardust '80 Plant.

Case 2: Pyrolysis gasification plant (including pre-treatment system and gas engine generator) stock material: Municipal Solid Wastes from the U.S.: 100 tonnes/day. Fig. 5 shows the schematic process flow of case 2.

In both cases, required electric power is assumed to be supplied by a gas engine generator fed by product gas from the gasification process.

In both cases, all the raw waste water coming from the product gas refiners is assumed to be burned in the combustion tower.

MSW is separated into two parts (group A and B) by a selective pulverizing classifier, see Appendix 2). After the ferrous metal is removed, group B is shredded to a size less than 150 mm and fed to the reactor, where it is gasified. A fraction of the product gas is consumed by the gas engine generator to meet all demands for electricity in the plant.

The material in group A is assumed to be discharged as residues to be landfilled together with the incombustibles (glass, metals, etc.) discharged from both reactors.

Table 10 lists the results of separation of U.S. municipal refuse predicted by the SPC simulation model. This model was developed on the basis of the results of the processing of over 20,000 tonnes of Japanese MSW taken from various sources. The calorific value of the group B refuse is calculated as 4,600 Kcal/kg-dry (gross) or about 8300 BTU per pound.

Table 10. Results of separation of U.S. municipal refuse predicted by Selective Pulverizing Classifier simulation model

	Input refuse[a]	Group A	Group B
Paper	42.7	28.1	51.7
Glass	11.1	47.0	3.1
Metal	11.1	1.1	3.0
Plastics	9.9	0.7	13.5
Rubber	3.3	0	4.5
Textile	5.9	0.1	8.1
Wood	11.9	8.6	14.2
Garbage	3.5	13.6	1.3
Others	0.6	0.8	0.6
Total	100	100	100
Fraction	100	18.8	72.9[b]
Moisture	19.0	24.2	19.4

unit: %

[a] Municipal solid waste of Baltimore County Md.

[b] The remaining 8.3% is recovered as ferrous metal by magnetic separators.

(2) Predicted gas and energy recovery rates

Figures 6-9 show the mass and heat balances applicable to case 1 and case 2, respectively. The efficiency of the plant for each case was computed to be:

	Case 1	Case 2
Gasification rate	52.8 %	47.1 %
Gas energy recovery rate	43.6 %	35.1 %
Total energy recovery rate	57.1 %	40.5 %

Tables 11-13 list the results of the calculations applicable to required utilities, recovered materials, site area, personnel and capital costs.

Table 11. Utility Requirements

	Case 1	Case 2
City water (t/d)	969	560
Industrial water (t/d)	1790	1620
Chemicals ($Ca(OH)^2$) (t/d)	5.3	8.3
Sand[a] (t/d)	4.8	7.4

[a] Average particle size is 0.56 mm.

Table 12. Recovered materials

	Case 1	Case 2
Fuel gas[a] (Nm^3/d)	305×10^3	172×10^3
Steam[b] (t/d)	811	407
Ferrous metal (t/d)	0	70.5

[a] Calorific value of product gas
Case 1: 5650 kcal/Nm^3 (630 Btu/ft^3)
Case 2: 5500 kcal/Nm^3 (620 Btu/ft^3)

[b] Steam pressure: 16 kgf/cm^2

These volumes of fuel gas and steam are those predicted to be recovered after all other plant energy demands (including electricity) have been taken into account.

Table 13. Capital cost and personnel for operation and daily maintenance

		Case 1		Case 2		
		Pyrolysis system	Gas--engine	Pre-treatment system	Pyrolysis system	Gas engine
Capacity of total system		RDF 1000 t/d		MSW 1000 t/d		
Capacity of pyrolysis system		250 t/d x 4 trains		243 t/d x 3 trains		
	Equipment	24,326	3,100	6,562	33,077	3,078
Capitol cost (x $10^3$$)	Construction Semi-total	16,956 41,282	400 3,500	4,298 10,860	15,032 48,109	400 3,478
	Total	44,782		62,447		
Personnel	Operator	4	1	2	3	1
for	Laborer	6	0	3	5	0
operation	Crane man	0	0	2	0	0
and	Shifts/day	(3)	(3)	(2)	(3)	(3)
maintenance (person)	Total/day	33		41		
Necessary site area for construction		36,000 m^2		43,000 m^2		

Appendix 1

Pretreatment Subsystem

The pretreatment subsystem handles such operations as the weighing, receiving, storing and classifing of the collected refuse mixture so as to supply each backend subsystem with stock material. The main equipment in the pretreatment subsystem is the selective pulverizing classifier (SPC).

The classifier has a circular shape and is approximately 3 meters in diameter and about 8 meters in length. The input refuse mixture, delivered by conveyor is fed into the classifier, where the refuse is classified via passing through a trommel. The classified refuse is dropped out onto other conveyor belts provided below the classifier and carried to each subsequent subsystem. This equipment comprises a cylindrical rotary screen drum and a pulverizing scraper plate. The latter is incorporated into the former but rotates at a speed different from that of the rotary screen drum. Thus, the refuse is pulverized and classified simultaneously.

The first items of input refuse to be pulverized and classified with the rotary screen drum are garbage, soil and sand and glass and chinaware, all of which are relatively brittle; the refuse so classified is referred to as Group I material. The remainder of the refuse passes through the screen drum; water is sprayed onto the refuse at the center of the pulverizing scraper plate in the second screen drum. This water is absorbed by paper and other materials in the refuse. The resulting mixture has lower impact resistance and shearing force than the dry material. Thus, the mixture can easily be pulverized on the pulverizing scraper plate and selectively discharged from the second rotary screen drum. The material so discharged is referred to as Group II. The remaining refuse consists of plastics, metal cans, etc., which are highly resistant to impacts and shearing forces.

This material is referred to as Group III and is discharged at the furthermost end of the drum. Table "a" lists the refuse components as classified by means of the selective pulverizing classifier.

Table a. Example of separation of municipal refuse by selective pulverizing classifier system.

Refuse contents	Input refuse	Composition after separation Group 1 Fraction	Group 2 Fraction	Group 3 Fraction
Plastics	11.4	0.9	2.9	38.3
Textile	4.1	0.3	1.1	13.8
Wood, bamboo	3.8	2.9	2.0	7.0
Paper	38.5	25.9	81.5	18.0
Garbage	10.9	19.8	5.3	0.5
Straw, leaves	0.8	0.9	0.9	0.4
Leather, rubber	0.5	0.1	0.0	1.5
Metals	5.9	0.6	0.4	20.4
Glass, stone, ceramics	15.0	30.3	2.4	0.0
Dirt, miscellaneous substances	9.1	17.3	3.5	0.0
Total	100.0	100.0	100.0	100.0
Moisture	50.0	63.2	64.8	30.2

The pretreatment subsystem includes the following features:

(a) Capable of simultaneously pulverizing and classifying refuse in a single process and with a low rate of power consumption.

(b) Group I is composed mainly of garbage, which may be used for compost.

(c) Group II is composed mainly of paper, which may be used for pulp.

(d) Group III is composed mainly of plastics, and is thus a favorable feedstock for gasification.

(e) In response to changes in input refuse composition or in requirements for classification, the pretreatment subsystem permits easy alteration of the degree of classification. This control is achieved by changing the feedrate of refuse in the drum and/or the relative velocity of both the pulverizing scraper plate and the drum.

Appendix 2

Selective Pulverizing Classifier (SPC2)

1. Functions

   (1) Separation capability: SPC2 can classify municipal refuse into two groups, i.e., compostable materials and non-compostable materials.

   (2) Crusher: SPC2 can crush compostable materials in municipal refuse into sizes suitable for aerobic fermentation. Excessive crushing is avoided, because it not only wastes power, but may also rupture dry batteries in the waste could cause heavy metal contamination in the compost.

   (3) Bag-breaker: SPC2 can cope with refuse collected in plastic bags or boxes.

2. Features.

   (1) SPC2 can be used directly to apply suitable moisture for aerobic fermentation.

   (2) SPC2 tends to operate properly even if bulky items such as metal appliances are charged.

   (3) Entanglement of long strings around the rotary shaft, a major problem with conventional shredders, is said to be eliminated by the wrap prevention device specifically developed for this machine. This feature renders the manual removal of strings unnecessary and greatly reduces maintenance time.

   (4) Unlike conventional trommel type screens, this sieve is unlikely to become clogged because of cleansing function of scrapers.

   (5) Because of its very low speed, this classifier creates far less wear, noise and vibration than conventional high-speed shredders. The SPC2 which incorporates both pulverizing and classification by screening in one machine, developed with full support of the Agency of Industrial Science and Technology (AIST of MITI of Japanese government) and was awarded the Directors Prize of the Ministry of Science and Technology in 1977, and the Mechanical Institute Prize in Japan 1978.

3. Brief description of equipment

   (1) General. Pretreatment for composting refuse requires three basic functions: 1) elimination of non-compostable materials, 2) size reduction without operating leakage from dry batteries, and 3) moisture adjustment.

1) The elimination of non-compostable materials such as plastics, metals, textiles, etc., from raw refuse before fermentation yields the following important advantages:

   a) The capacity of the fermenter can be increased substantially by the elimination of non-compostables, particularly plastic films and the like, which have a large specific volume.

   b) Heavy metals contained in the non-compostables may dissolve into the compost during the course of the preliminary fermentation, thus lowering the pH value of the final product.

   c) Bulky textiles and long strings contained in the refuse often become entangled in the stirring mechanism of the usual type of fermenter.

2) Size reduction to obtain a large specific surface of the material is preferable for fast fermentation. Excessive pulverization, however, must be avoided, since it not only requires a large amount of power but also ruptures dry batteries leakage from which may cause heavy metal contamination in the compost.

3) The moisture of the pretreated compostable material must generally be kept within a limited range (about 40 to 60% depending on the type of fermenter) which is suitable for aerobic fermentation.

(2) The Selective Pulverizing Classifier (SPC2): Based on the preceding three requirements, the SPC2 (Selective Pulverizing Classifier) was developed. The SPC2 takes advantage of differences in the resistance to destruction of different material; both pulverization and classification by screening can be accomplished with the aid of this one machine. As shown in appendix figure 1, the SPC2 consists of a rotating drum screen and a scraper rotating at a different speed inside the screen.

As the refuse is fed continuously into the rotation drum, almost all of the garbage (food waste) and brittle materials such as dirt, glass and ceramics, and a fraction of the (flimsy) paper are pulverized into particles or flakes and pass through the screen (A Group). The remaining residues consisting of plastics, metals and textiles etc., are discharged through the open end of the drum (B Group).

In the case of dry refuse input, moisture can be increased by spraying water from a tap built into the central shaft so that the optimum water content for fermentation of A Group material can be easily obtained. Additional moisture can also increase the paper concentration in A Group owing to the resultant strength reduction of the paper.

In the case of wet input (considerable amounts of wet garbage), an increase in the relative speed between the drum and scraper produces a considerable increase in the pulverizing effect and in the concentration of dry paper in A Group which in turn decreases its total moisture content.

Unlike the conventional shredder, which completely shreds all the refuse, this classifier discharges B Group materials from the drum end following the process of selective pulverization. This refuse remains close to its orginal size. Almost all of the dry batteries contained in the refuse maintain their original shape and remain sealed.

Small batteries are discharged into the A Group without being shredded. These batteries are separated by the magnetic separator. The size of pieces of glass and ceramics discharged into A Group is extremely large compared with that produced by conventional shredding. These remnants can be easily removed after fermentation.

4. Engineering Aspects.

SPC2 consists of a rotating drum screen equipped with ridge projections, rotating scrapers inside the drum screen, and a drive unit which drives both the drum screen and the rotating scraper by means of one motor protected by a safety device.

The motion of the rotating drum screen is controlled by means of a chain driven by the motor followed by a reduction gear. The RPM value is kept constant within the range of 20 to 40 rpm.

The rotating scraper located inside the rotating drum screen, is controlled by means of a belt driven by the SPC2's single motor and a infinitely variable transmission. The RPM of the rotating scraper is variable within the range of 40 to 80 rpm.

The rotational direction of the scraper is the same as that of the drum screen, but the rotational speed is different. Therefore, shear stress arises and pulverization occurs in the region between the scraper and the ridge projection mounted in the inside of the drum screen.

5. Separation Performance

Table "b" lists test results for separating a sample of municipal refuse with the SPC2. As seen in this table, garbage (kitchen refuse) was concentrated by a factor of about two, and plastics and textiles, the main components of RDF, were almost completely discharged through the open end of the drum as B Group.

Accordingly, the SPC2 was judged to be suitable separating equipment for the plant producing both RDF and compost from municipal refuse. Since the particle diameter of the compostable materials (A Group) from SPC2 is pulverized and homogenized to a size of about 20 to 40 mm, extremely good fermentation can be achieved.

6. Utility Requirement.

Electricity consumption of the SPC2 is 10 to 15kwh/tonne (input refuse).

Table b. Test Result of SPC2

	Municipal Refuse	A Group		B Group	
	Composition (%)	Composition (%)	Classification (%)	Composition (%)	Classification (%)
Paper	56.3	58.1	49.1	55.0	50.9
Garbage	14.5	29.4	96.6	1.0	3.4
Textile	10.0	0.6	3.6	18.5	97.0
Wood	2.6	1.7	31.0	3.4	69.0
Dirt	0.8	1.7	100.0		0.0
Glass	3.3	6.9	100.0		0.0
Metal	8.2	0.8	5.0	14.9	95.0
Plastics	4.3	0.8	10.0	7.2	90.0
Total (Dry)	100.0	100.0	100.0	100.0	
Moisture (Content) (%)	49.3	54.5		40.2	

[a] Each rate of classification described in this table assumes that sewage sludge is not mixed with refuse. Mixing refuse and sludge causes an increase of classification rate of paper in the A Group.

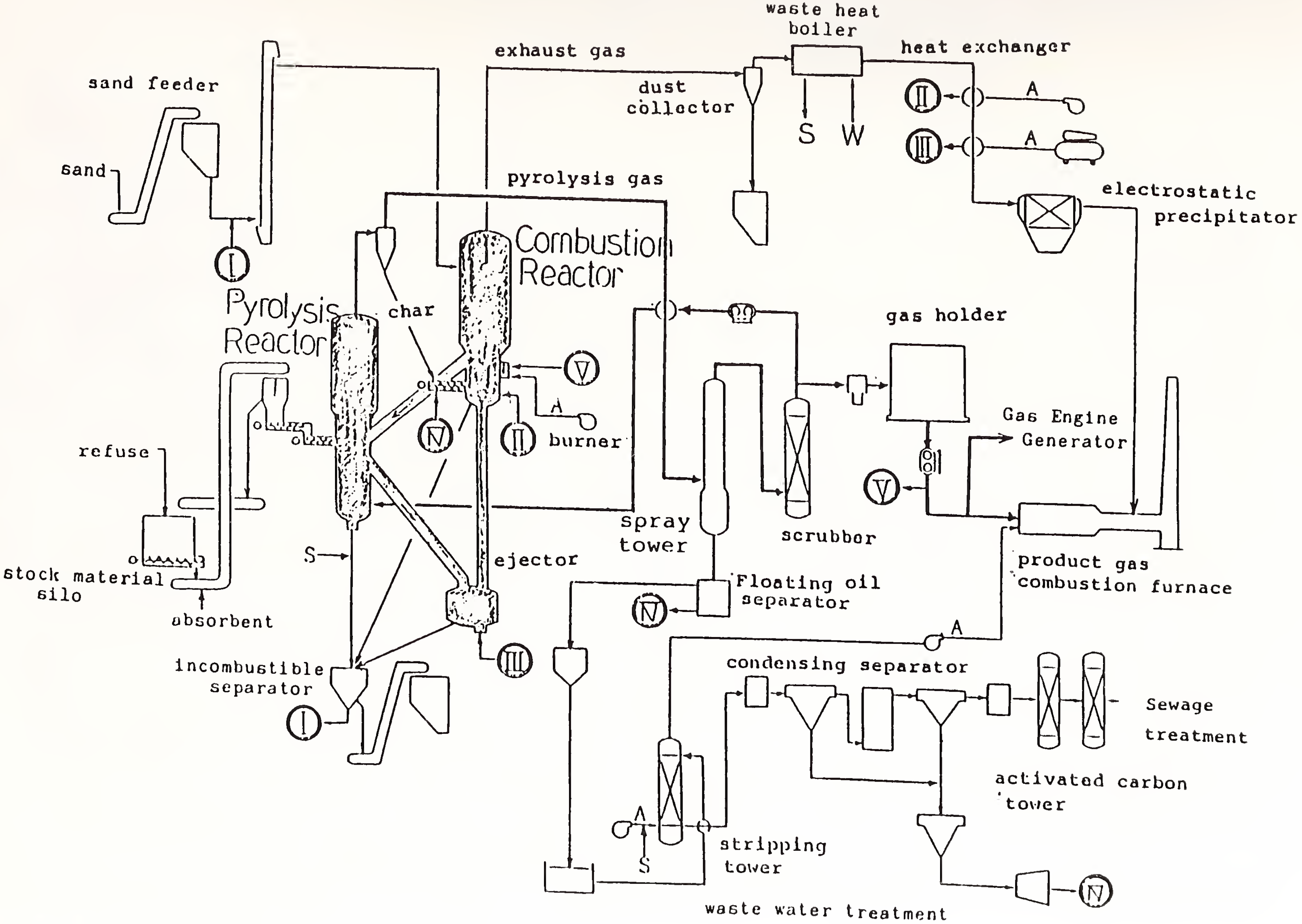

waste heat boiler
heat exchanger
exhaust gas
sand feeder
dust collector
S
W
Ⅱ
Ⅲ
A
A
sand
pyrolysis gas
electrostatic precipitator
Ⅰ
Combustion Reactor
Pyrolysis Reactor
char
gas holder
Ⅴ
A
burner
Ⅳ
Ⅱ
Gas Engine Generator
refuse
Ⅴ
spray tower
scrubber
S
ejector
stock material silo
absorbent
Floating oil separator
product gas combustion furnace
Ⅳ
A
incombustible separator
Ⅲ
condensing separator
Ⅰ
Sewage treatment
activated carbon tower
A
S
stripping tower
Ⅳ
waste water treatment

Figure XIII.1. Two-bed pyrolysis system process flow.

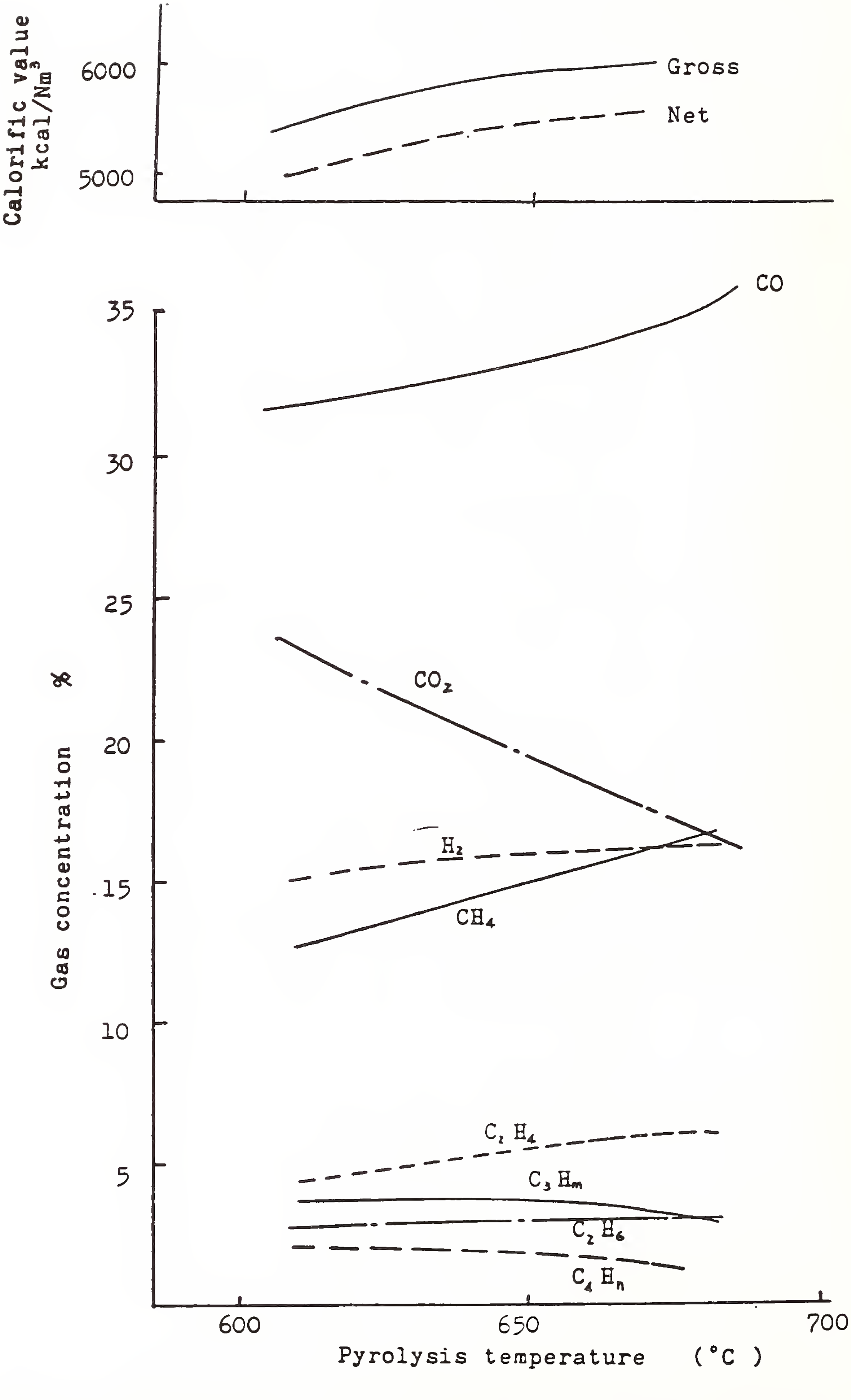
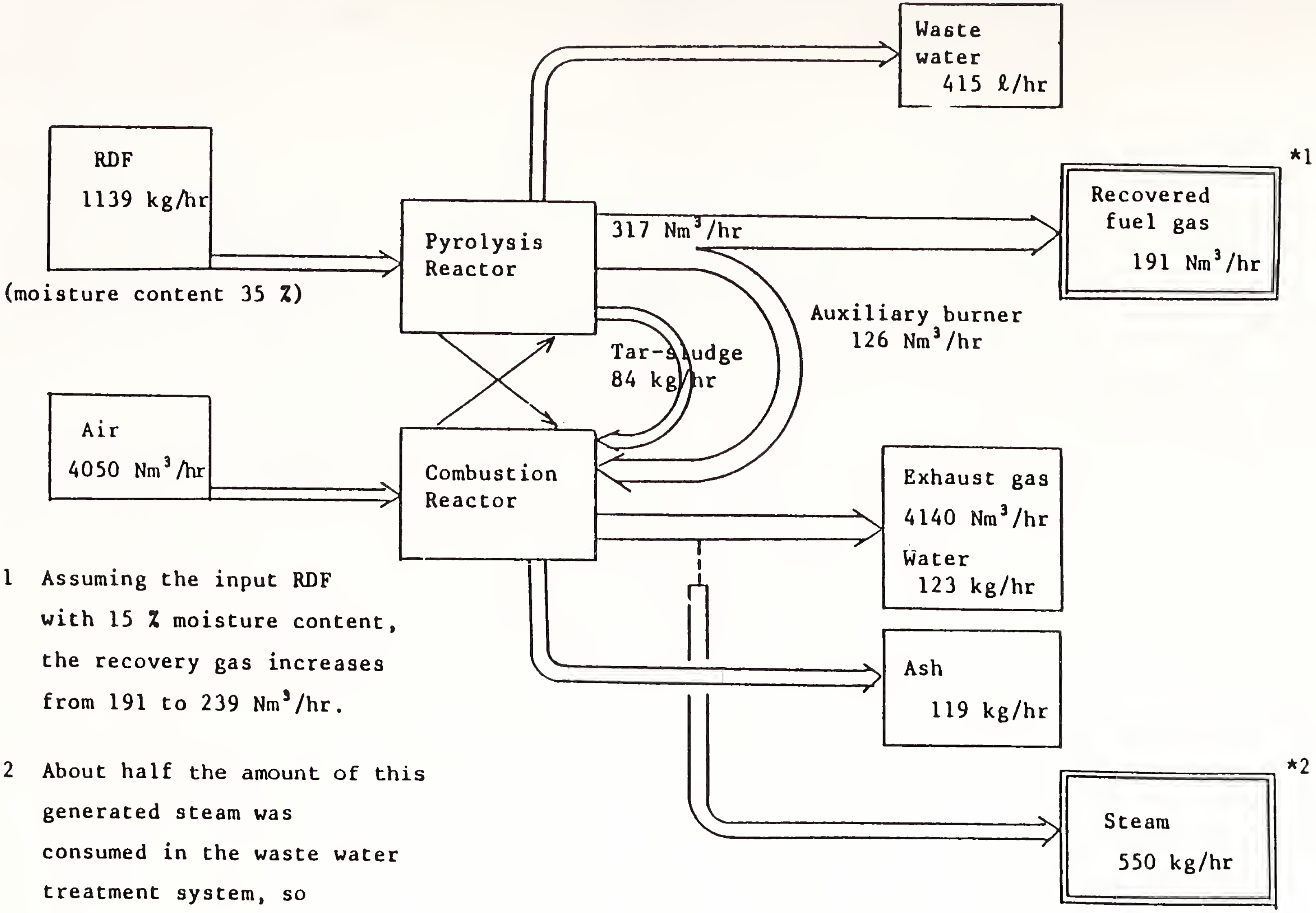


Figure XIII. 2. Gas concentration vs. pyrolysis temperature.


RDF
1139 kg/hr
(moisture content 35 %)
Air
4050 Nm³/hr
Pyrolysis Reactor
Combustion Reactor
Waste water 415 ℓ/hr
317 Nm³/hr
Recovered fuel gas 191 Nm³/hr
*1
Tar-sludge 84 kg/hr
Auxiliary burner 126 Nm³/hr
Exhaust gas 4140 Nm³/hr
Water 123 kg/hr
Ash 119 kg/hr
Steam 550 kg/hr
*2

*1 Assuming the input RDF with 15 % moisture content, the recovery gas increases from 191 to 239 Nm^3/hr.

*2 About half the amount of this generated steam was consumed in the waste water treatment system, so 270 kg/hr of steam were ultimately recovered.

Figure XIII.3. Mass balance.

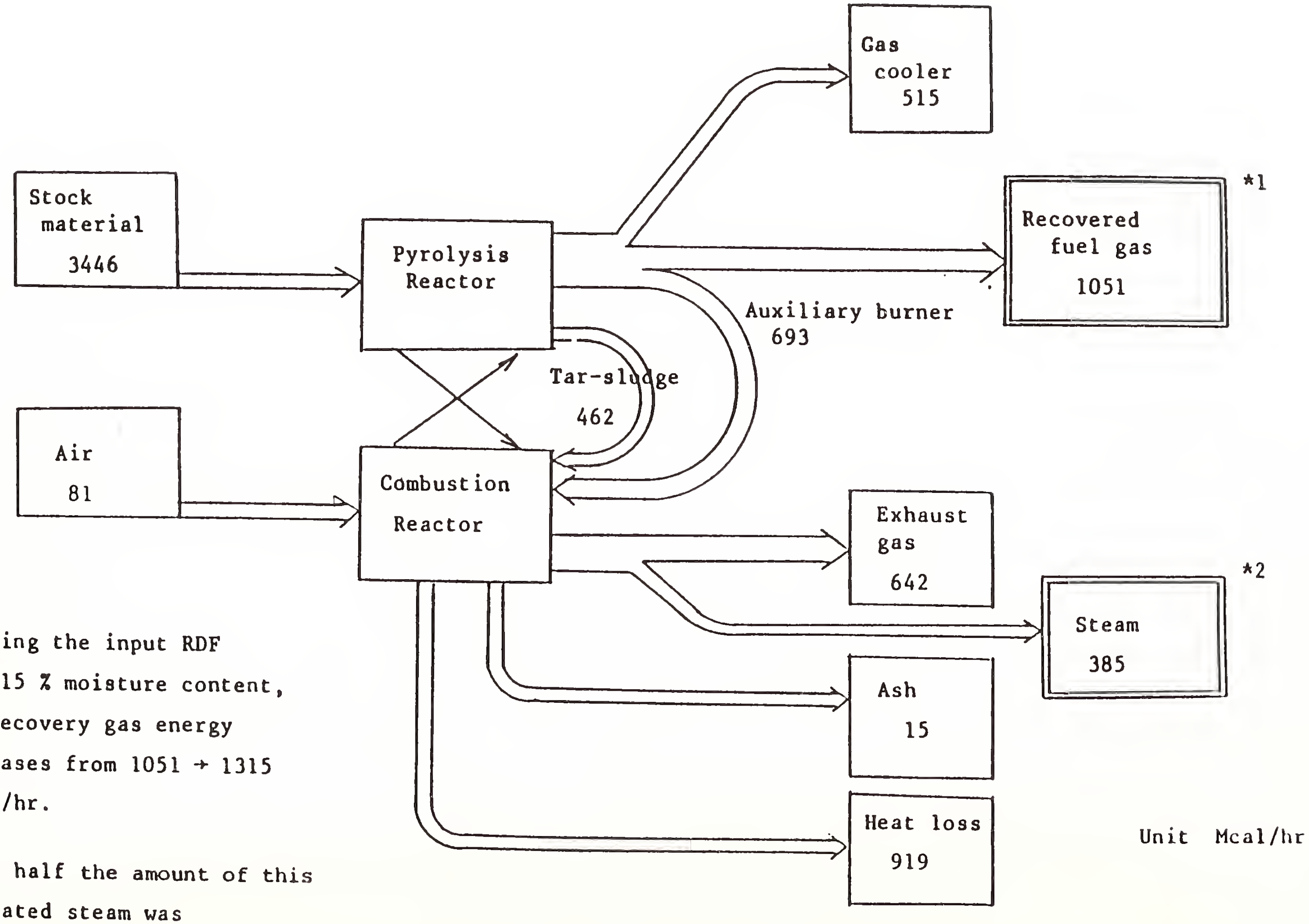
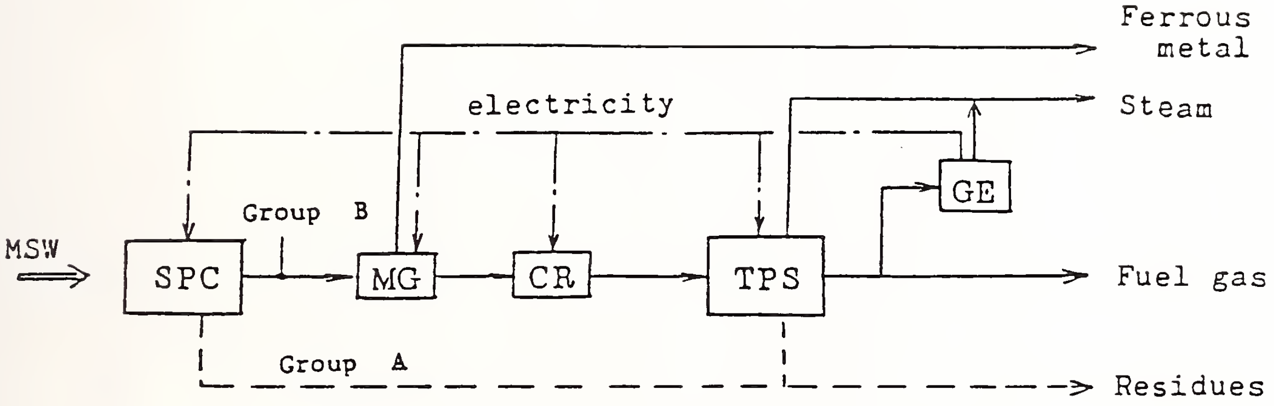

Stock material 3446
Pyrolysis Reactor
Air 81
Combustion Reactor
Tar-sludge 462
Auxiliary burner 693
Gas cooler 515
Recovered fuel gas 1051
*1
Exhaust gas 642
Steam 385
*2
Ash 15
Heat loss 919
Unit Mcal/hr

Figure XIII.4. Heat balance.

*1 Assuming the input RDF with 15 % moisture content, the recovery gas energy increases from 1051 → 1315 M cal/hr.

*2 About half the amount of this generated steam was consumed in the waste water treatment system, so 196 M cal/hr of energy were ultimately recovered.


Ferrous metal
electricity
Steam
GE
Group B
MSW
SPC
MG
CR
TPS
Fuel gas
Group A
Residues

SPC ; Selective Pulverizing Classifier

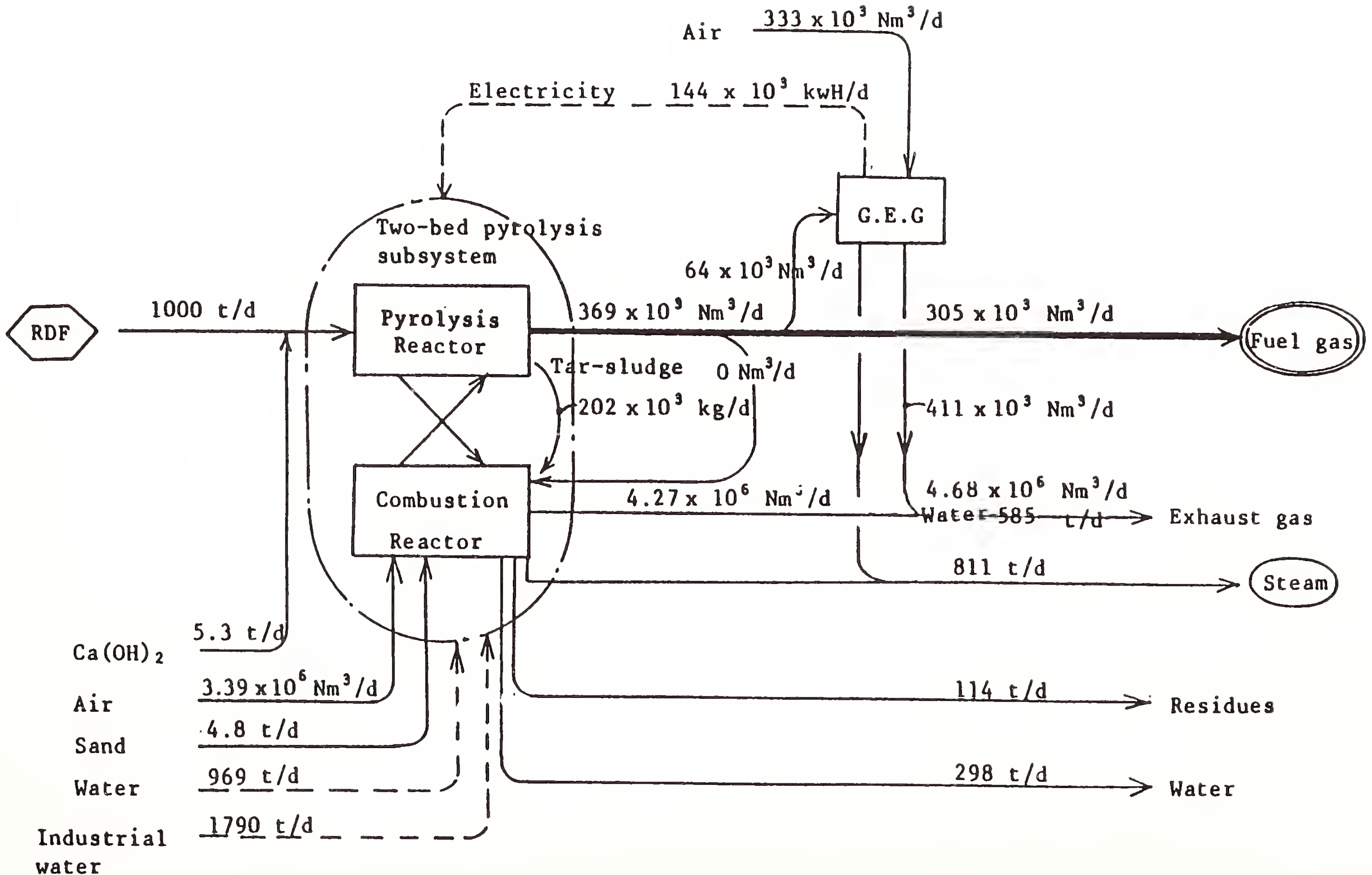
MG ; Magnetic Separater

CR ; Crusher

TPS ; Two-bed Pyrolysis system

GE ;Gas Engine Generator

Figure XIII.5. Schematic process flow.


Air
333 x 10³ Nm³/d
Electricity
144 x 10³ kwH/d
G.E.G
Two-bed pyrolysis subsystem
64 x 10³ Nm³/d
RDF
1000 t/d
Pyrolysis Reactor
369 x 10³ Nm³/d
305 x 10³ Nm³/d
Fuel gas
Tar-sludge
0 Nm³/d
202 x 10³ kg/d
411 x 10³ Nm³/d
Combustion Reactor
4.27 x 10⁶ Nm³/d
4.68 x 10⁶ Nm³/d
~~Water 585 t/d~~
Exhaust gas
811 t/d
Steam
Ca(OH)₂
5.3 t/d
Air
3.39 x 10⁶ Nm³/d
Sand
4.8 t/d
Water
969 t/d
Industrial water
1790 t/d
114 t/d
Residues
298 t/d
Water

G.E.G. ; Gas Engine Generator

Figure XIII.6. Mass balance (Case 1).

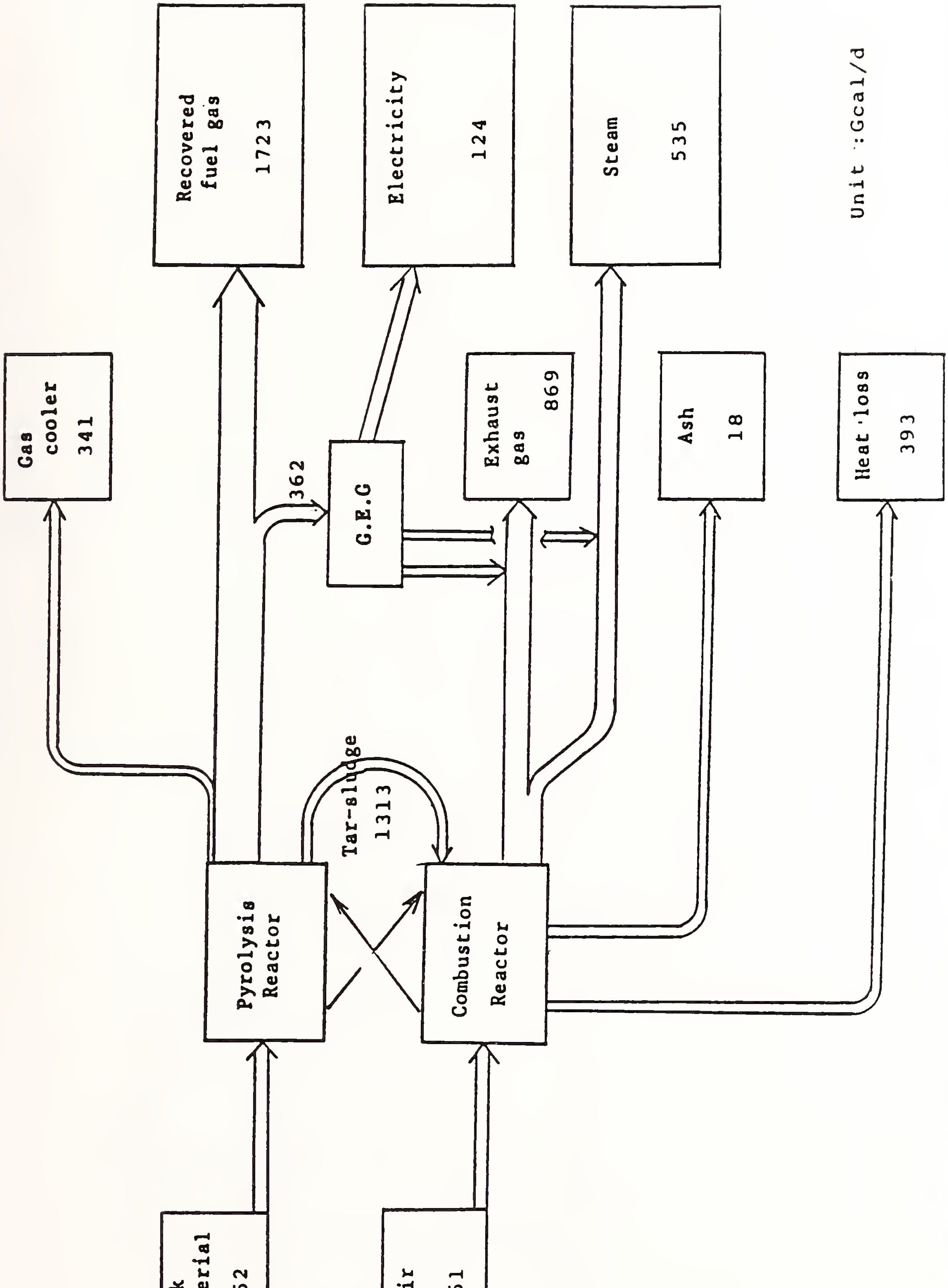

Stock material 3952
Air 51
Pyrolysis Reactor
Combustion Reactor
Tar-sludge 1313
Gas cooler 341
362
G.E.G
Exhaust gas 869
Ash 18
Heat loss 393
Recovered fuel gas 1723
Electricity 124
Steam 535
Unit :Gcal/d

Figure XIII.7. Heat balance (Case 1).

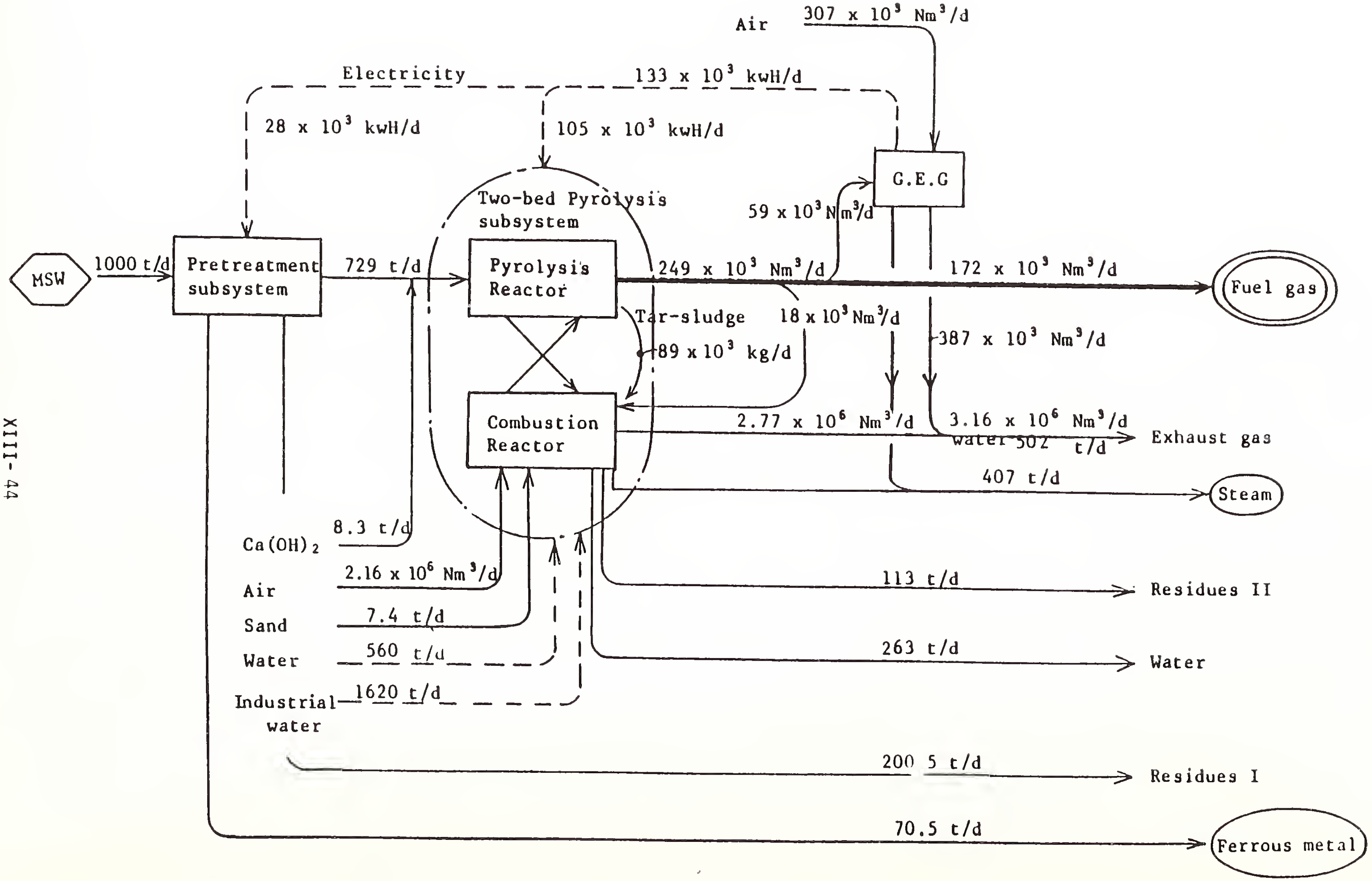

MSW
1000 t/d
Pretreatment subsystem
Electricity
28 x 10³ kwH/d
133 x 10³ kwH/d
105 x 10³ kwH/d
Air
307 x 10³ Nm³/d
G.E.G
729 t/d
Two-bed Pyrolysis subsystem
Pyrolysis Reactor
Combustion Reactor
59 x 10³ Nm³/d
249 x 10³ Nm³/d
172 x 10³ Nm³/d
Fuel gas
Tar-sludge
18 x 10³ Nm³/d
89 x 10³ kg/d
387 x 10³ Nm³/d
2.77 x 10⁶ Nm³/d
3.16 x 10⁶ Nm³/d
water 502 t/d
Exhaust gas
407 t/d
Steam
Ca(OH)₂
8.3 t/d
Air
2.16 x 10⁶ Nm³/d
Sand
7.4 t/d
Water
560 t/d
Industrial water
1620 t/d
113 t/d
Residues II
263 t/d
Water
200.5 t/d
Residues I
70.5 t/d
Ferrous metal

Figure XIII.8. Mass balance (Case 2); (G.E.G. means Gas Engine Generator).

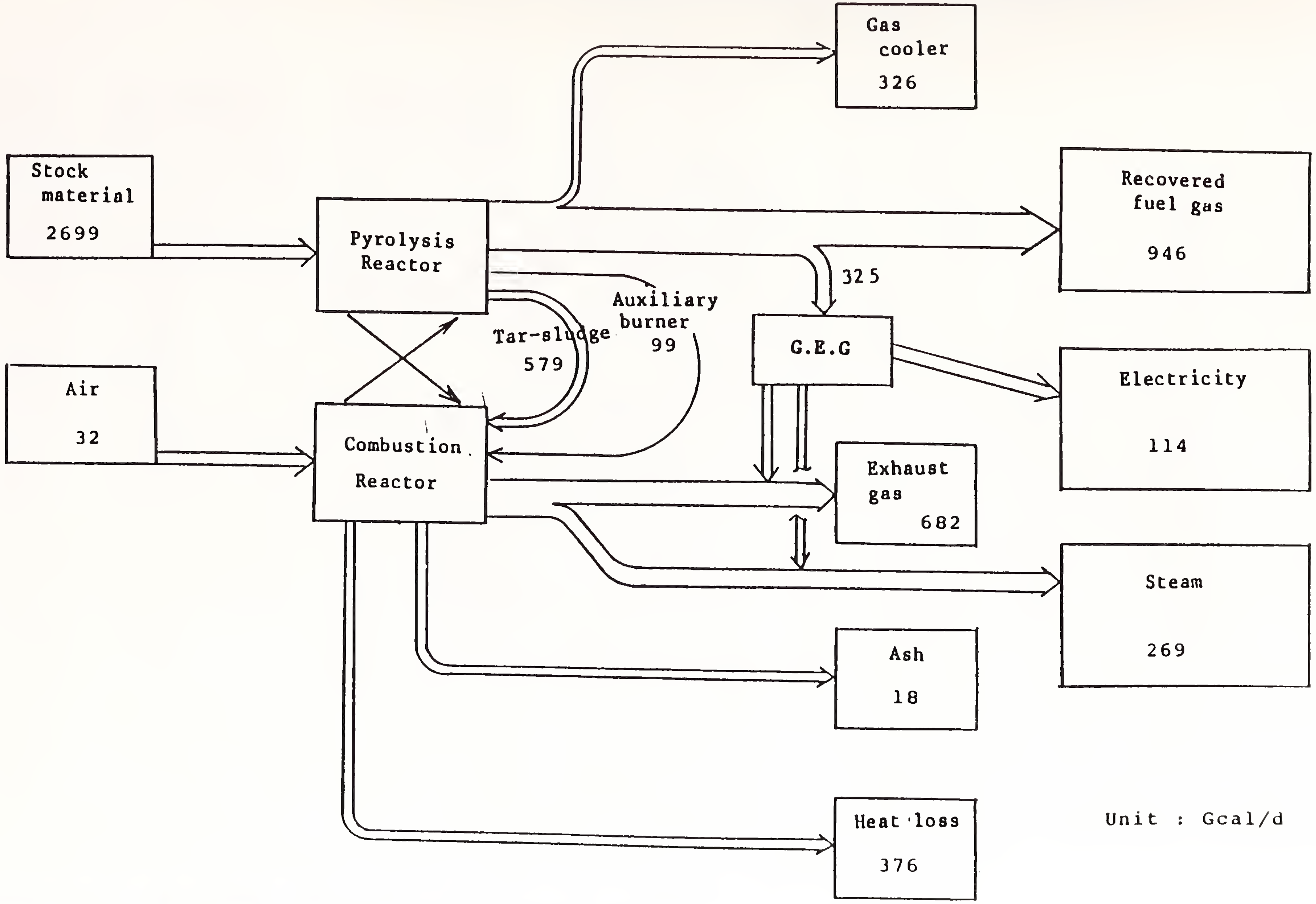
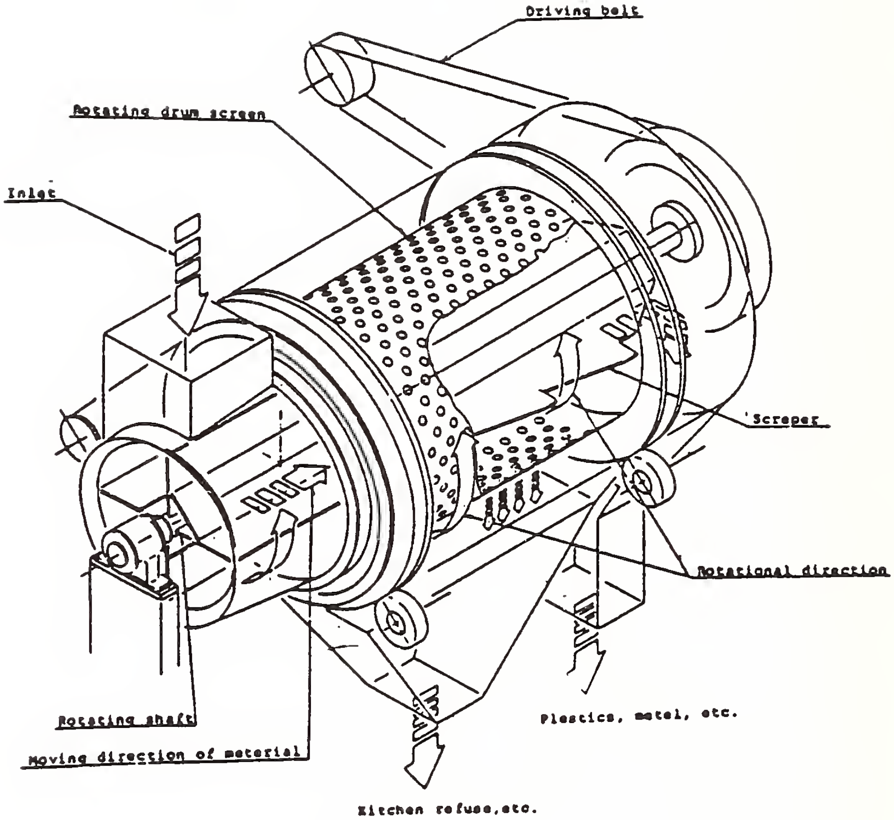

Gas cooler 326
Stock material 2699
Recovered fuel gas 946
Pyrolysis Reactor
325
Auxiliary burner 99
Tar-sludge 579
G.E.G
Air 32
Electricity 114
Combustion Reactor
Exhaust gas 682
Steam 269
Ash 18
Heat loss 376
Unit : Gcal/d

Figure XIII.9. Heat balance (Case 2).


Driving belt
Rotating drum screen
Inlet
Scraper
Rotational direction
Plastics, metal, etc.
Rotating shaft
Moving direction of material
Kitchen refuse,etc.

Appendix Figure 1.

APPENDIX XIV. A SIMPLE DEGREE OF HAZARD SYSTEM FOR HAZARDOUS WASTES

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The purpose of this brief exposition is to suggest a method for classifying waste treatment, storage and disposal facilities with respect to potential hazard posed by the existence of the facility. Existing, proposed and inactive or abandoned facilities can be classified by the method to be described; final disposal may be by thermal destruction or burial.

HAZARD-CONCENTRATION RELATIONSHIPS

The dose experienced by some population or ecosystem as a result of hazardous waste operations or storage--via any path of escape from a facility--needs to be related to observed instances of harm or the possibility of harm at some undefined future date. In all of the following discussions, assume that the exposure or dose occurs as a result of a hazardous waste facility. Further, assume that the exposure can be measured accurately and that the sampling procedure is statistically valid; these are admittedly large assumptions.

Toxicity testing for incidence of adverse effects in animals and humans as related to exposure or dosage usually results in a sigmoidal or S-shaped dose-hazard curve (see fig. 1). Here zero dose means zero hazard. But, the probability of harm to the exposed population as a function of very low dose or levels of exposure is extremely difficult to measure or to predict theoretically as indicated in figure 1. Note that "hazard" suggests a threat posed by chance or something largely beyond one's control while "risk" may imply voluntary exposure to harm or loss.

Consider models for extrapolating from measurable exposure data to the hazard at lower exposures. In one experiment, some 24 000 female mice were subjected to a known bladder and liver carcinogen in order to study dose responses down to a one-percent tumor incidence, i.e., the concentration of the carcinogen which would cause one mouse in 100 to develop liver or bladder tumors[1]. Results of these tests were not especially enlightening. For example, a linear extrapolation and a Weibull model were applied to the data.

For a one-in-a-million risk ($P = 10^{-6}$) of liver cancer in the mice, an 0.045 part-per-billion dose of the carcinogen was predicted by the linear model; the Weibull model predicted a 4.5 part-per-billion dose for $P = 10^{-6}$ or an exposure of 100 times greater for the same risk[1].

The EPA Carcinogen Assessment Group has stated that:

> "There is no really solid scientific basis for any mathematical extrapolation model which relates carcinogen exposure to cancer risks at the extremely low level of concentration that must be dealt with in evaluating the environmental hazard."

With respect to the prediction of "time-to-tumor" data, there is no agreement between available models. Results are different, and reliable prediction appears impossible at present[1].

As stated by the Congressional Office of Technology Assessment:

> "The accuracy of the relation between exposure and incidence (of adverse effects) is always limited. Practical restraints on the number of animals that can be tested means that the data are always subject to significant experimental error; it also means that only relatively high incidences, almost always greater than 10%, can be measured in the experiments. There is also no agreement about which mathematical models best extrapolate from the exposure levels measured in studies to those encountered in the environment. Linear models, which assume that incidence is proportional to exposure at low exposure levels, are used by Federal agencies."[1]

Note that use of a linear model as compared to other possible extrapolation models, e.g., log-normal, log-logistic, Weibull, predict a higher probability for harm at lower exposure levels. As a practical matter, there is often no alternative to the linear model, since there are essentially no empirical data to support other extrapolation schemes.

Some of the technical difficulties will be apparent from an examination of Table I in which two objective and competent groups of scientists attempted to define cancer hazard from drinking-over an entire lifetime-water containing one part-per-billion (one microgram per liter) of known carcinogens. The table purports to indicate the number of persons per million exposed who are likely to fall victim to cancer from drinking this water. Note that in several cases, a tenfold to hundredfold difference exists between the two estimates. Data taken from Table I are shown plotted in figures 2 and 3 assuming a linear relationship between concentration and cancer risk, in excess of that which would obtain if C_x were zero, i.e.,

$$P_R = m_x C_x \quad \text{where} \tag{1}$$

P_R is the proportion of the exposed population who are likely to suffer the adverse effect, m_x is the slope of the linear relationship obtained by dividing the value tabulated (Table I) by C_x of 1 PPB, and C_x is the concentration of the constitutent, x, which is presumed to pose the hazard.

DETERMINING THE EXPOSED POPULATION

Determining the exposed population, i.e., the group subjected to higher than baseline concentrations of the substances from a site, is no simple challenge. In principle, the various paths by which substances might reach the group can be identified. Monitoring, which relies on qualitative and quantitative determinations at various points away from the site, can be implemented. Thus, what--if anything--is escaping and how much will be known as a function of distance from the site. When the slope of the concentration against distance curve changes upward, the boundary for a particular path can be located. Wind, other climatic factors, and water flow patterns may well alter the results over a period of time. Airborne or rain-based factors may enter. Concentrations of substances produced by other means than the waste disposal site may intervene, e.g., from the plants generating the waste or other sources. Thus, attempting unambiguous identification of who is exposed to higher concentrations of potentially harmful substances from a waste disposal site is likely to be exceedingly difficult, time-consuming, expensive, and inaccurate.

ESTIMATION OF HAZARD

But, even if the exposed population, N, could be accurately determined and the hazard of cancer or other disease were known accurately, prediction of adverse events due to hazardous waste requires a probabilistic estimation scheme. Since the hazards tend to be fairly small in a probabilistic sense, the Poisson distribution function may represent an appropriate model.

Consider a fixed unit of time, T, in which certain events may occur. Assume that the events occur independently and that for periods of time, Δt, which are very short in comparison to T, the probability of one event is proportional to the length of time Δt, i.e., is equivalent to $C\Delta t/T$, where "C" is constant during the time period T. Assuming the probability of two or more events in time Δt is negligible and defining Ct/T as λ:

$$F(k) = \frac{\lambda^{k}\ell^{-\lambda}}{k!} \qquad (2)$$

In other words, the probability that "k" events will occur before time "t" is given by the Poisson distribution.

If the time interval is taken to be a human being's lifetime and if the "event" is taken to be the occurrence of an adverse effect due to exposure to the hazardous waste constitutents, then the value of λ for an exposed population of human beings, N, can be estimated. Assume some proportion, "p" of individuals in the population, N, suffer an adverse effect due to exposure to the hazardous waste; the remaining proportion, (1-p), do not suffer the adverse effect. If the product Np is equal to or less than five, then the parameter "λ" in equation (2) can be taken as Np. Since the time interval is taken to be a lifetime, the value of λ is the mean number of occurrences of the event, i.e., adverse effect due to exposure to hazardous waste, within the exposed population. The probability of occurrence of the event within the specified time interval will be very small compared with the total number of occurrences of such events, and the Poisson distribution thus may represent an appropriate model for our purposes.

If 1000 persons were exposed to 1.1 PPM of chloroform in their water according to figure 2, the hazard (or p) is 10^{-3} and $\lambda = Np = (1000)(10^{-3}) = 1.0$. Note equation 2 indicates that the probability that no one in the exposed population will be adversely affected, P_o, is simply:

$$P_o = e^{-\lambda} \qquad (3)$$

Furthermore, if the linear risk relationship of equation 1 is utilized to determine the proportion of individuals likely to be adversely affected due to the presence of constituent x at concentration C_x, then

$$\lambda = m_x N C_x \qquad (4)$$

since $\lambda \equiv NP_R$, i.e., λ is related to population size. Hence, if the slope, m_x, the exposed population, N and the concentration C_x can be determined:

$$P_o = \exp[-(m_x N C_x)] \qquad (5)$$

The parameter P_o, the probability that no one in the exposed population is adversely affected, provides an appropriate figure of merit for ranking the potential hazard from a site. But uncertainties in determining the value of N and C_x for specific situations and the more general problem of ascertaining values of "m" for potentially harmful substances suggest that large uncertainties in determining P_o are likely to occur. In any event, the uncertainty ΔP_o can be estimated as:

$$|\Delta P_o| = \left| P_o \ell n P_o \left[\left(\frac{\Delta m_x}{m_x}\right)^2 + \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta C_x}{C_x}\right)^2 \right]^{\frac{1}{2}} \right| \qquad (6)$$

Equation (6) assumes errors are independent. Furthermore, the approximation to $|\Delta P_o|$ becomes worse as the values of $(\Delta m/m)$, $(\Delta N/N)$, $(\Delta C_x/C_x)$ become large. Nevertheless, equation (6) can be used as an indicator to show that unacceptably large values of $|\Delta P_o|$ are likely to occur.

Members of the exposed population can point to the difficulties in ascertaining m, N, and C_x as a means to exclude proposed facilities, or to demand immediate remedial action--which may or may not be warranted--in the case of existing facilities. Finally, uncertainties in P_o could increase the chances for persons associated with the facility to be held liable under state and/or Federal statutes.

While the concept of utilizing P_o as an appropriate means to classify possible risk from the facility is appealing, practical application of equation 5 could be exceedingly difficult. Therefore, some means to deal in a practical sense with site specific characteristics in an appropriate fashion is needed. In particular, the issues of "How clean is clean?" for inactive sites as well as reasonable performance measures for existing and proposed facilities need to be addressed. Furthermore, whatever method is selected must provide a means to account for cost effectiveness of proposed actions based on the results of applying the method. The remainder of this paper will propose a method which:

- o Utilizes P_o as the basic measure of hazard.
- o Takes into account site specific characteristics.
- o Is amenable to fairly rigorous uncertainty analysis.
- o Provides guidance as to the monitoring and analytical regime required for a specific facility.
- o Avoids the problems associated with determining the "exact" population exposed, N and with determining the slope of the hazard relation, m_x.
- o Utilizes--in most instances--critically evaluated data as inputs.

THE EXTENDED PRELIMINARY POLLUTANT LIMIT VALUE METHOD

The Preliminary Pollutant Limit Value (PPLV) method for human health effects was developed by Rosenblatt and co-workers at the U.S. Army Medical Bioengineering Research and Development Laboratory. These authors have published a series of articles and reports detailing the basis of the method as well as various practical applications[2-7]. In addition, basic chemical data required for input to the model have been critically evaluated and published[8]. Therefore, only a brief summary of the basic PPLV method will be presented here:

> "Initially, each pathway for transfer of a pollutant from the environment to man is treated as if it involved either (a) one environmental compartment, or (b) a series of successive compartments containing the pollutant at equilibrium. Transfer from the final compartment to humans is considered a non-equilibrium process occurring at an assumed rate. A PPLV is that concentration of the pollutant in the first compartment that is calculated to result in reception by the target human being of exactly the acceptable daily dose, D_T, via one or more pathways. The basic concept may be modified as the situation requires."[7]

Figures 4 and 5 indicate the basic processes and assumptions in schematic form. Table II presents some results from reference 2 giving some PPLV values for seven compounds in soil. Rosenblatt has indicated that PPLV's are not standards or criteria but they are values which can be used to choose alternative courses of action for:

- Developing renovation options for contaminated areas.
- Suggesting limits on land utilization near facilities.
- Specifying monitoring conduct.
- Establishing analytical sensitivity requirements.

The basic premise is that once a PPLV is found for a specific area in which the treatment-storage-disposal facility is presumably contained, if the concentration of the constituents can be reduced to PPLV or are never allowed to exceed PPLV, then the interaction of humans with the area or its products is "safe" for any exposed population, i.e., the acceptable daily dose of the pollutants will not be exceeded. However, the questions of what occurs if PPLV is exceeded or if the cost of achieving PPLV is prohibitively large remain to be dealt with.

If PPLV is achieved, the exposed population is presumed to have some extremely small probability to suffer adverse effects. Note well that PPLV is site specific and only the population for which the particular PPLV has been computed is included in this assumption. If linearity between the proportion of affected individuals and PPLV is assumed, then

$$P_R = (\mathrm{PPLV})m_x \qquad (7)$$

But since PPLV supposedly includes N, then, in this case,

$$P_R = \lambda = (\mathrm{PPLV})m_x \qquad (8)$$

If PPLV is achieved, then the probability that an adverse effect will occur is supposedly very small. If an assumption is made that this probability is to be 10^{-4}, then m_x may be estimated as:

$$m_x = 10^{-4}/\mathrm{PPLV} \qquad (9)$$

If P_R were taken as something other than 10^{-4}, clearly m_x would then be different. Hence, under these assumptions, λ at PPLV is 10^{-4} and P_o which is $\exp(-\lambda)$ is 0.9999. Thus, if PPLV is achieved there is a 99.99% chance that no one in the exposed population will be harmed. If PPLV is exceeded we assume that λ increases linearly with concentration of constituent x, i.e.:

$$\lambda = 10^{-4}\, C_x/\mathrm{PPLV} \qquad (10a)$$

and

$$P_o = \exp[-(10^{-4}\ C_x/PPLV)]. \tag{10b}$$

The assumption that λ increases linearly with C_x seems likely to provide a reasonable rate of increase for λ in view of the previous discussion pertaining to extrapolation models. The concept of acceptable daily dose, D_T, is related to lifetime hazard in the PPLV formulation so that equation (10) is consistent with our previous assumptions regarding the applicability of the Poisson process as well as with the PPLV basis. Nevertheless, the assumption of independence of N remains to be investigated in more detail. Figure 6 shows P_o vs. the ratio $(C_x/PPLV)$. Clearly, figure 6 indicates that C_x^o can exceed PPLV by a considerable amount before P_o falls to 0.95. But the uncertainty in P_o due to uncertainties in the computation of PPLV and the measurement of C_x still needs to be considered:

$$\frac{\Delta P_o}{P_o} = \left(\frac{10^{-4}C_x}{PPLV}\right)\left[\left(\frac{\Delta C_x}{C_x}\right)^2 + \left(\frac{\Delta(PPLV)}{PPLV}\right)^2\right]^{\frac{1}{2}} \tag{11}$$

If a term, E, is defined as:

$$E \equiv \left[\left(\frac{\Delta C_x}{C_x}\right)^2 + \left(\frac{\Delta(PPLV)}{PPLV}\right)^2\right]^{\frac{1}{2}} \quad \text{, then} \tag{12}$$

$$\frac{\Delta\lambda}{\lambda} = E \tag{13}$$

As with equation (6), the errors are assumed independent and the approximations for $\Delta P_o/P_o$ and $\Delta\lambda/\lambda$ become worse as $\Delta PPLV/PPLV$ and/or $\Delta C_x/C_x$ increase. If some estimates for "E" can be made, then cumulative probability as a function of E can be estimated as well. With regard to the term $(\Delta C_x/C_x)$, the National Bureau of Standards (NBS) evaluated analytical data obtained in the vicinity of the Love Canal in Niagara Falls, New York[9]. In addition, NBS has investigated several aspects of the challenges to the analytical chemist posed by low levels of constituents in variable matrices[10]. Based upon these results, a reasonable range for the uncertainties in determining the concentration of constituent X is $0<\Delta C_x/C_x \leq 5$, with a most probable value being about 0.5 to 1.

So far as uncertainties in PPLV are concerned, Rosenblatt and co-workers have discussed sources of error in some detail but have not carried out a formal quantitative analysis. Three major sources of uncertainty are:

- The assumption of equilibrium between environmental compartments.

- The statistical extrapolations yielding "safe" doses of various constituents.

- Uncertainties in data with respect to likely fate of various constituents in various environments. For example, the following summarization indicates some relations of physicochemical properties to environmental behavior:

Physical Chemical Data	Related To:
1. Solubility in Water	Leaching, degree of adsorption, mobility in environment.
2. Latent Heat of Solution	Adsorption, leaching, vaporization from surfaces.
3. Partition Coefficient	Bioaccumulation potential, adsorption by organic matter.
4. Hydrolysis	Persistence in environment and biota.
5. Ionization	Route and mechanism or adsorption or uptake, persistence, interaction with other molecular species.
6. Vapor Pressure	Atmospheric mobility, rate of vaporization.

Reference 8 has considered both the availability and validity of current data in these areas. In addition, NBS has sponsored critical data reviews and original research aimed at improving these data$^{10-13}$ as have many other institutions. Given these uncertainties, a range for $\Delta(\text{PPLV})/\text{PPLV}$ of $0<\Delta(\text{PPLV})/\text{PPLV}\leq 15$ with the most probable value being about 5 or 6 seems to be reasonable. Nevertheless, more formal analysis is warranted to provide a better estimate.

From these considerations an approximate cumulative probability curve for the term $E \equiv \Delta\lambda/\lambda$ could be constructed. This curve is shown as figure 7; the curve indicates that there is a 95% cumulative probability that the term "E" does not exceed eleven. Given this result, the 95% upper bound for P_o can be calculated. Figure 8 shows this result as well as a repeat of equation (11b). These results indicate fairly clearly that if the ratio C_x/PPLV exceeds 100, then significant uncertainty in determining P_o may occur. Nevertheless, the 95% probability curve for the upper bound of P_o is available as a guide for personnel responsible for action at the site in question.

SUMMARY AND CONCLUSIONS

The Poisson statistical distribution is suggested as an appropriate approximation to the potential distribution of adverse effects in a population exposed to substances, such as toxic wastes. The probability that no one in the exposed population will be harmed is a reasonable ranking parameter to describe the hazard from a facility treating, storing and/or disposing of such wastes. However, this parameter may be subject to a number of uncertainties.

A method to estimate both the probability that no one in an exposed population will be adversely affected and the uncertainty associated with this estimate has been developed. The basis for this method is the preliminary pollutant limiting value (PPLV) technique developed by Rosenblatt and co-workers at the U.S. Army Medical Bioengineering Research and Development Laboratory. The PPLV method has been extended to consider the possible consequences of exceeding the safe limiting concentration calculated as PPLV. Results indicate effects for exceeding PPLV by factors up to 100. If PPLV is exceeded by more than 100, the probability for adverse effects in the exposed, population increases rapidly.

Nevertheless, the extended PPLV method can be applied to proposed, existing or inactive treatment, storage, and disposal facilities including those that dispose by thermal treatment or burial. Application of the extended PPLV method can provide a basis for selecting economically and environmentally sound options regarding activities associated with the site. Inactive or abandoned sites can also be ranked if necessary. Thus, the extended PPLV method might provide a simple degree of hazard system.

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Table I. Concentration of Drinking Water Contaminants and Calculated Excess Cancer Hazard of One-in-a-Million

	NAS[a]	CAG[b]
	ug/l[c]	ug/l[c]
Acrylonitrile	0.77	0.034
Arsenic	ND[d]	0.004
Benzene	ND	3.0
Benzo(a)pyrene	ND	ND
Beryllium	ND	0.02
Bis(2-chloroethyl)ether	0.83	ND
Carbon tetrachloride	9.09	0.086
Chlordane	0.056	0.012
Chloroform	0.59	0.48
DDT	0.083	ND
1,2-Dichloroethane	1.4	1.46
1,1-Dichloroethylene	ND	0.28
Dieldrin	0.004	ND
Ethylenedibromide	0.11	0.0022
ETU	0.46	ND
Heptachlor	0.024	2.4
Hexachlorobutadiene	ND	1.4
Hexachlorobenzene	0.034	ND
N-nitrosodimethylamine	ND	0.0052
Kepone	0.023	ND
Lindane	0.108	ND
PCB	0.32	ND
PCNB	7.14	ND
TCDD	ND	5.0×10^{-6}
Tetrachloroethylene	0.71	0.82
Trichloroethylene	9.09	5.8
Vinyl chloride	2.13	106.0

[a] Standardized to hazards from National Academy of Sciences Drinking Water and Health for consumption of 1 l/water/day.

[b] Recalculated to exclude aquatic food intake from Cancer Assessment Group, Ambient Water Quality Criteria. Standardized to 1 l/water/day intake.

[c] Average adult water consumption is 2 l/day.

[d] Not discussed.

SOURCE: Office of Technology Assessment.

Table II. Single Pathway PPLVs for Seven Compounds Originating in Soil
($mg\ kg^{-1}$)[a] after Reference [2]

Routes of Exposure	Chlorates	Arsenic Compounds	Mercury Compounds	Aldrin/ Dieldrin	Endrin	Toluene
Ingestion of water[b]	4.0	1.75	8.2×10^{-2}	3.5×10^{-3}	7×10^{-3}	53
Ingestion of food plants[c]	1.3×10^{-2}	56	2.6	0.22	0.44	1.7×10^{3}
Ingestion of foraging animals[d]	6.3×10^{3}	19	0.26	2.2×10^{-2}	4.4×10^{-2}	1.7×10^{2}
Ingestion of fish[e]	2.5×10^{4}	3.7	1.74×10^{-3}	7.4×10^{-5}	4.4×10^{-4}	4.2×10^{3}
Inhalation of vapors[f] (VD_o/C_{air})	0	63	5.4×10^{5}	4.6×10^{3} [g] 1.9×10^{2} [h]	17	1.56×10^{5}
Inhalation of particulates	∞	∞	3.0×10^{4}	6.3×10^{3}	1.3×10^{4} [i]	

[a] Except for inhalation of vapors.

[b] In the case of SPPPLVs derived for compounds originating in water, use MCL values.

[c] Root crop K_{wp} used, f = 0.1.

[d] Grain crop K_{wp} used, f = 0.2.

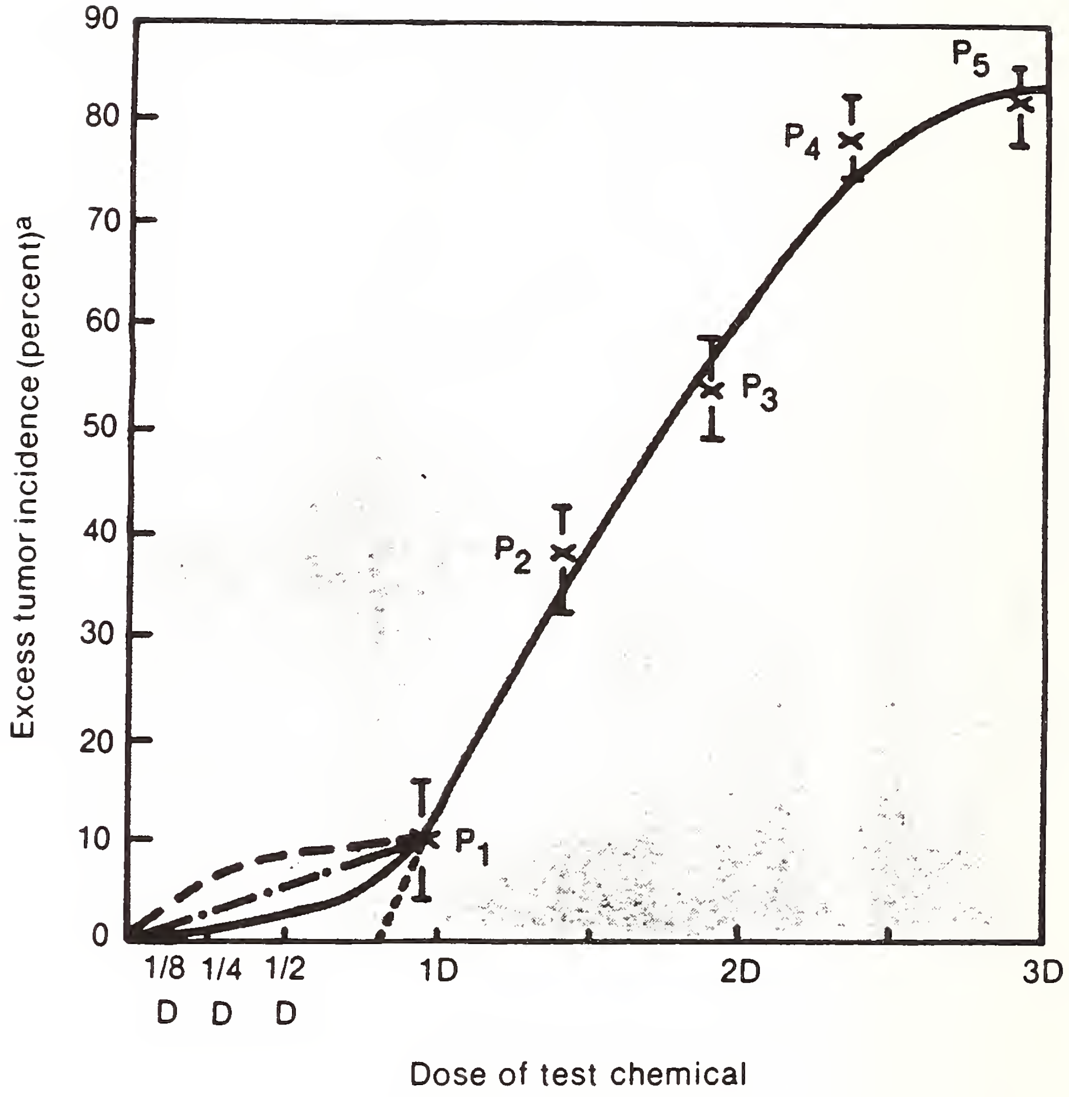
[e] Freshwater fish, f = 0.05.

[f] VD_o/C_{air} compares the saturation vapor pressure with the permissible concentration in air (which in all these cases is TLV/420).

[g] Value for aldrin.

[h] Value for dieldrin.

[i] Compound too volatile to adhere to particles.



[a]Excess tumor incidence (percent) is defined as:

$$\left(\frac{\text{tumors in exposed population}}{\text{number of exposed population}} - \frac{\text{tumors in control population}}{\text{number of exposed population}}\right) \times 100$$

——— a sigmoid dose-response curve; infralinear between O and P_1
—·—·— linear extrapolation
— — — supralinear extrapolation
------ line projected to a threshold

SOURCE: Office of Technology Assessment.

Figure XIV.1. A stylized dose-response curve and some extrapolated curves.

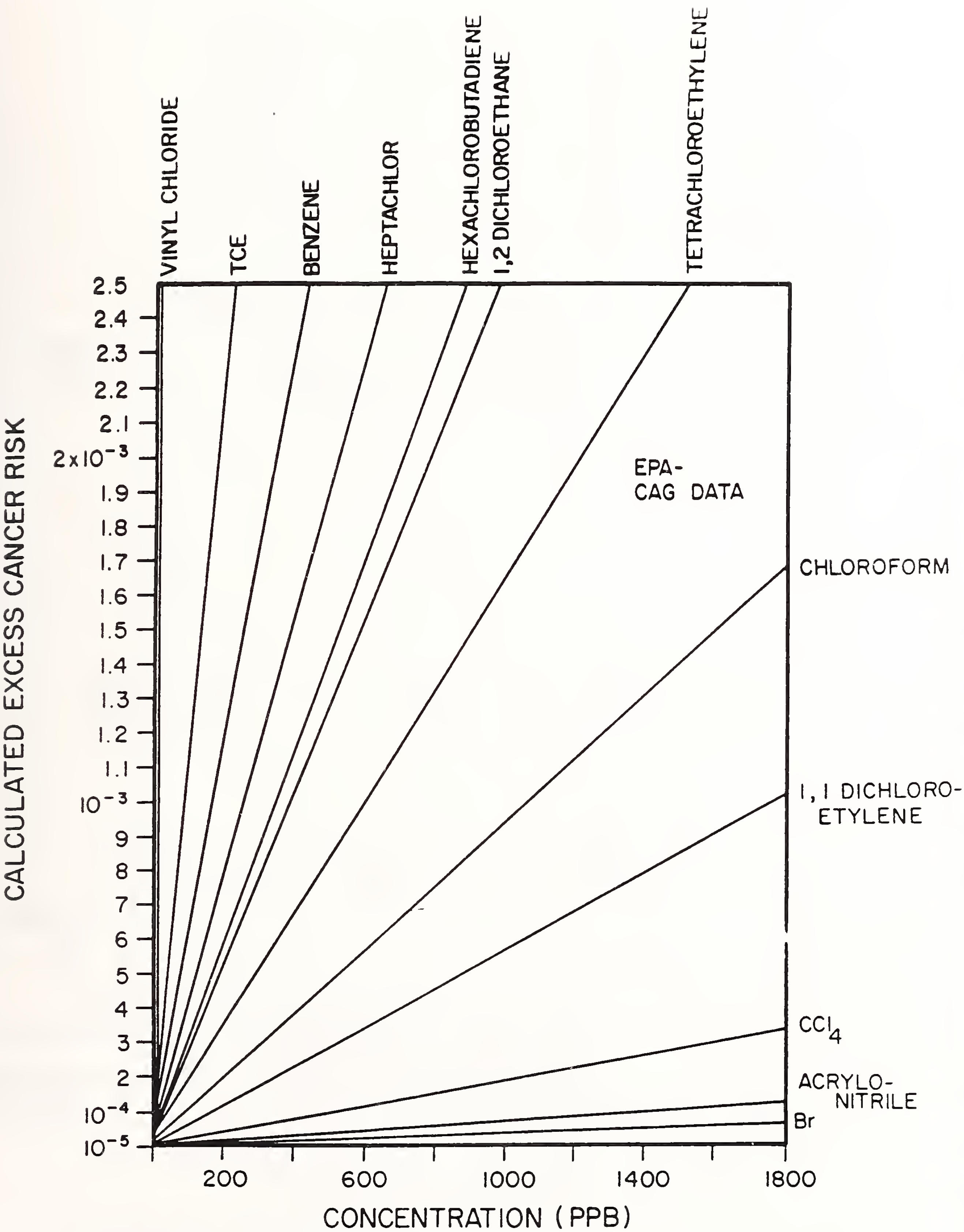


Figure XIV.2. Calculated excess cancer risk as a function of concentration of chemicals shown in drinking water. Assumes linear dose-response relationship in region shown. (EPA Carcinogen Assessement Group Data.)

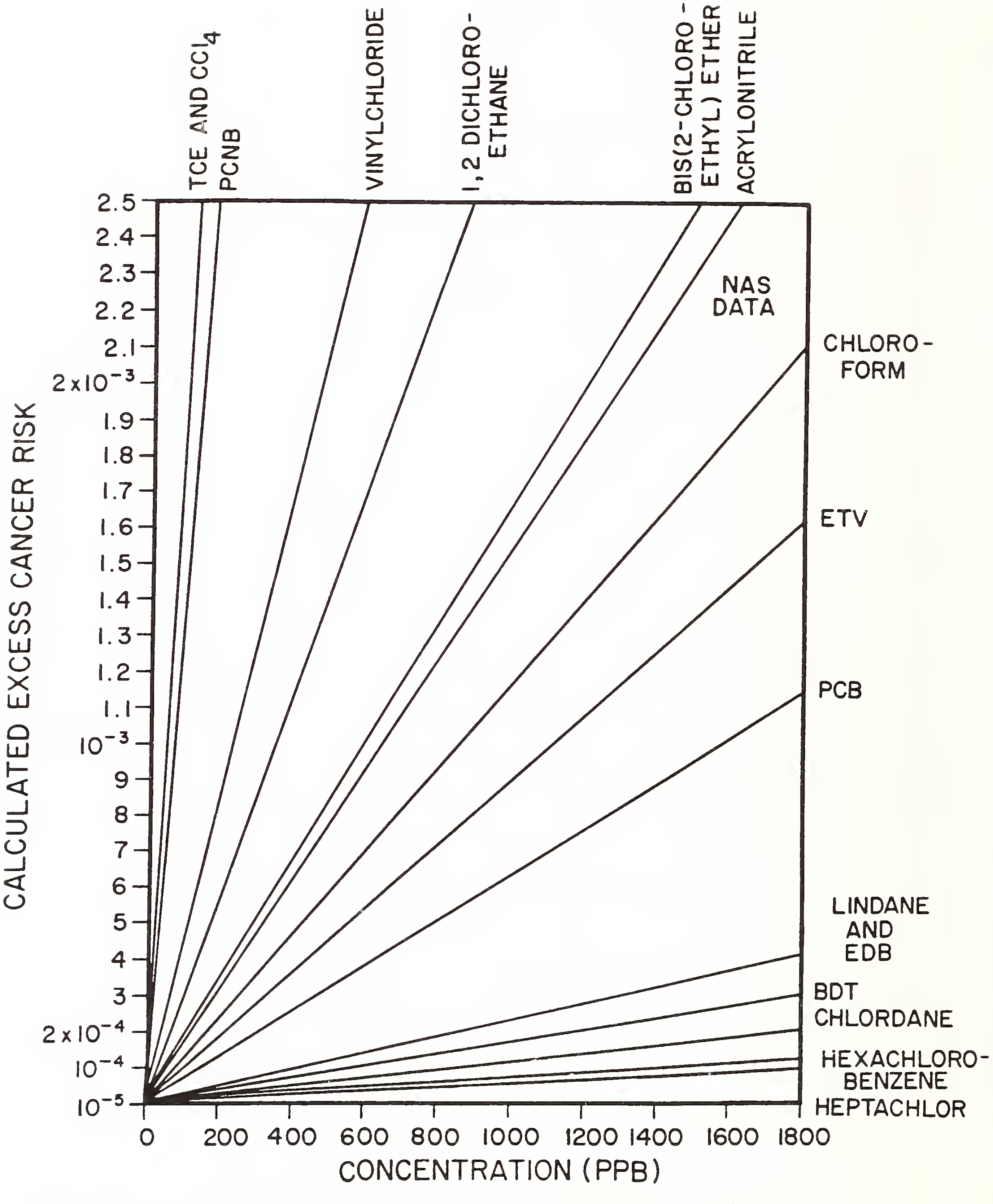


Figure XIV.3. Calculated excess cancer risk as a function of concentration of chemicals shown in drinking water. Assumes linear dose-response relationship in region shown. (National Academy of Sciences data.)

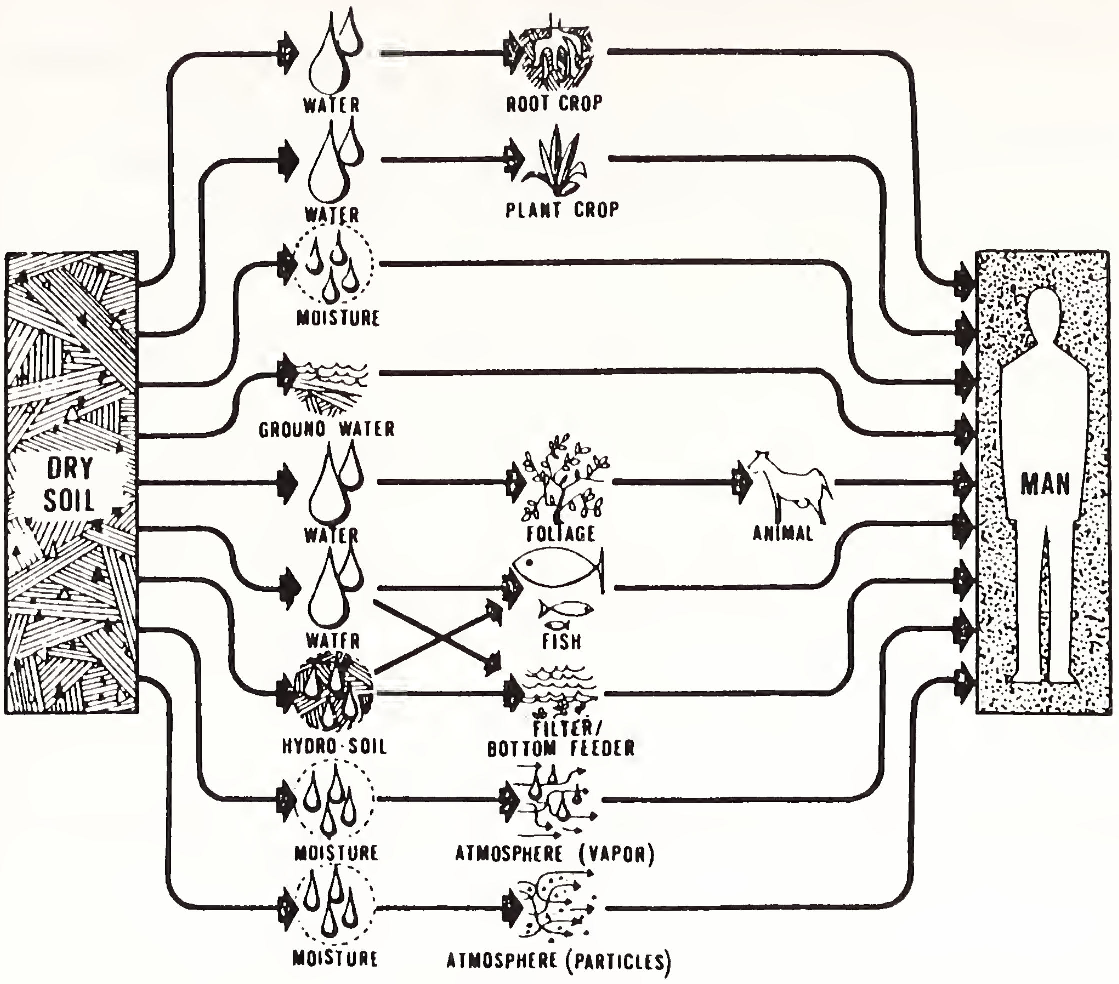
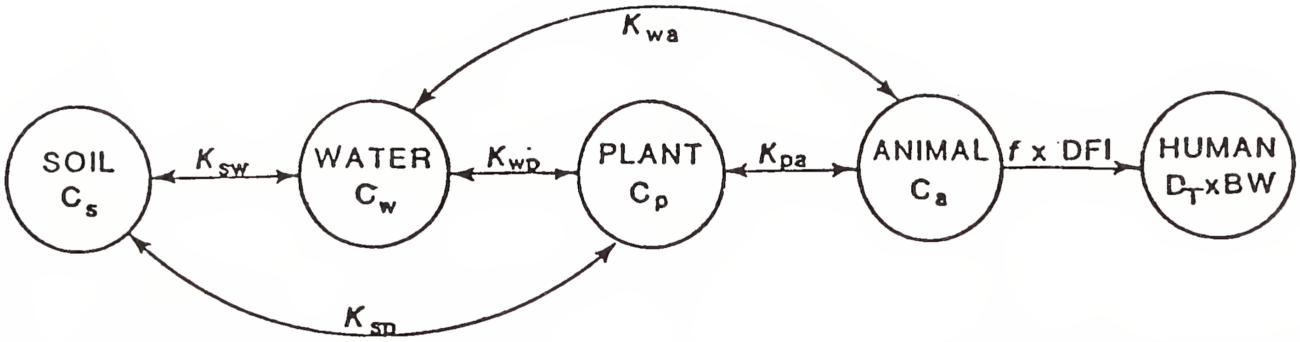

WATER
ROOT CROP
WATER
PLANT CROP
MOISTURE
GROUND WATER
DRY SOIL
WATER
FOLIAGE
ANIMAL
MAN
WATER
FISH
HYDRO-SOIL
FILTER/ BOTTOM FEEDER
MOISTURE
ATMOSPHERE (VAPOR)
MOISTURE
ATMOSPHERE (PARTICLES)

Figure XIV.4. Pollutant pathways from soil to man. (After reference 2.)


SOIL
C_s
WATER
C_w
PLANT
C_p
ANIMAL
C_a
HUMAN
D_TxBW
K_{sw}
K_{wp}
K_{pa}
f x DFI
K_{wa}
K_{sp}

Ⓐ In this fate model, the acceptable daily dose of toxicant, *Dt*, can be obtained from six sources of literature information. The equation for calculating the acceptable daily dose is:

$$D_T = \frac{f \times DFI \times C_a}{BW} = K_{pa} \times K_{wp} \times K_{sw} \times C_s \times f \times DFI/BW$$

$K_{sp} = K_{sw} \times K_{wp}$, etc.

$K_{sw} = C_w \div C_s$, etc.

Each K is an equilibrium constant for a pseudo-equilibrium between two compartments.

Figure XIV.5. Pollutant pathway from soil to man via water, plant, and animal compartments. (After reference 2.)

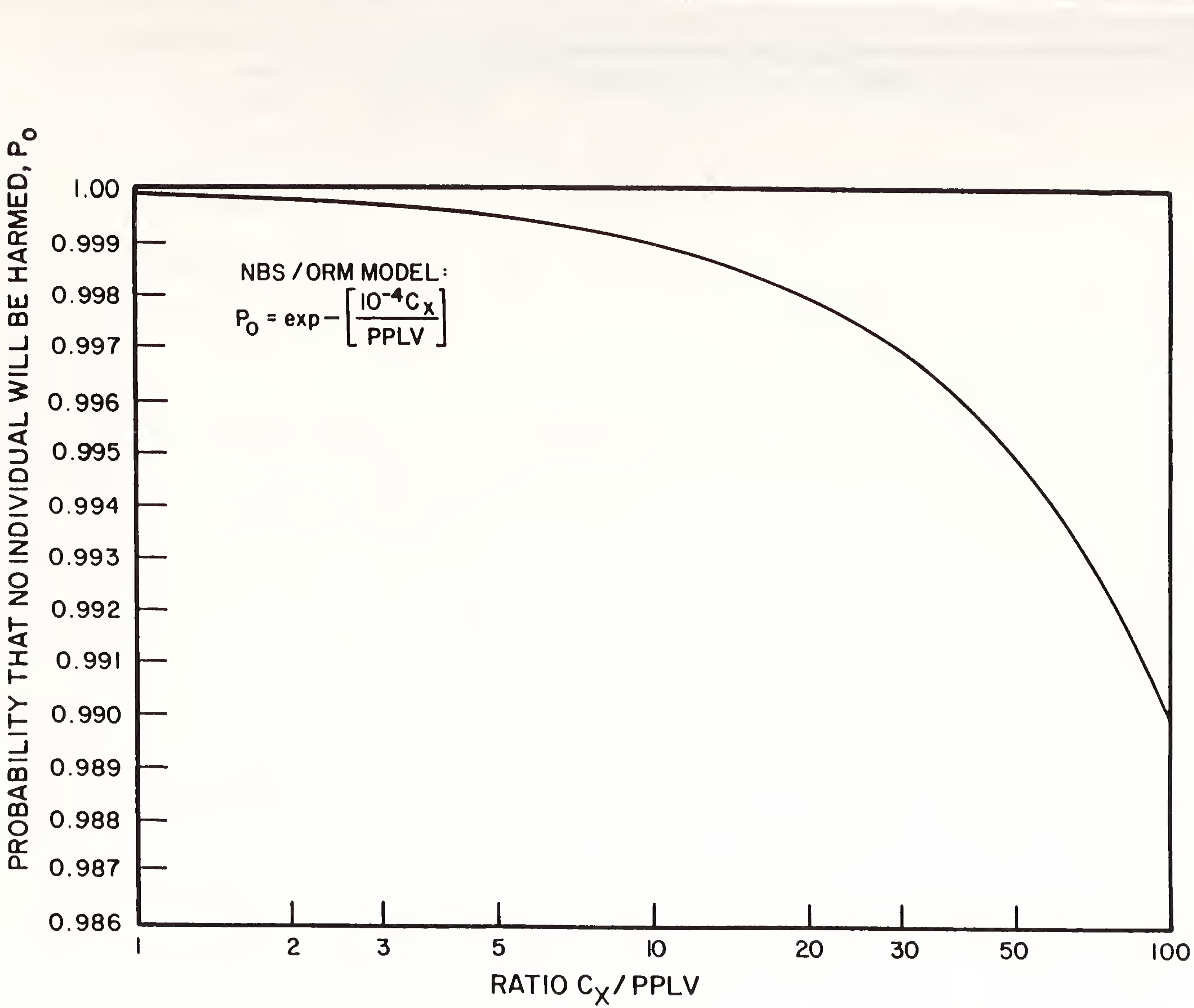
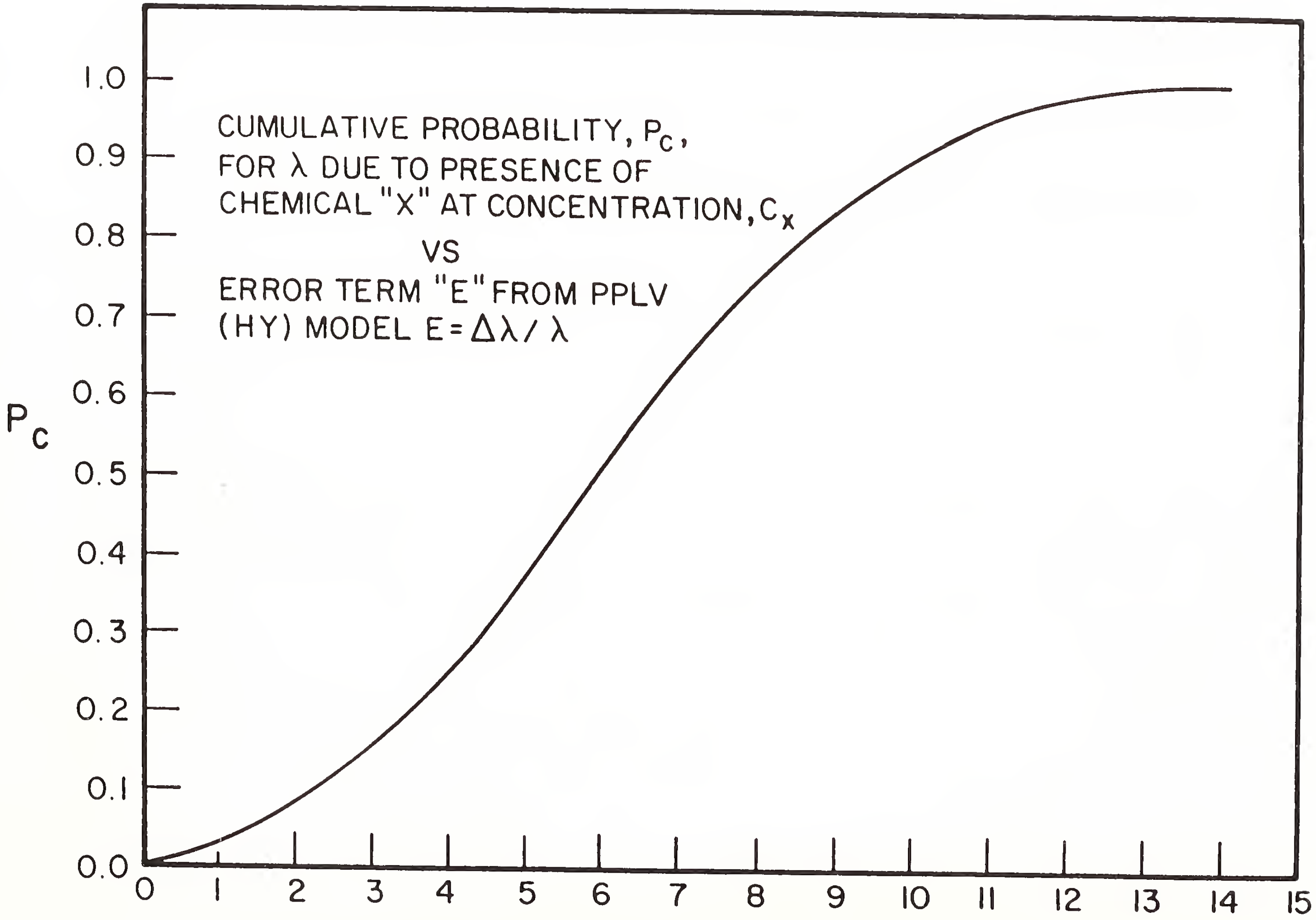


Figure XIV. 6. Probability that no individual in an exposed population is harmed as a function of the ratio C_X/PPLV.



$$E \equiv \left[\left(\frac{\Delta C_x}{C_x} \right)^2 + \left(\frac{\Delta PPLV}{PPLV} \right)^2 \right]^{1/2} = (\Delta\lambda / \lambda)$$

Figure XIV.7. Cumulative probability vs. error term for the extended PPLV method.

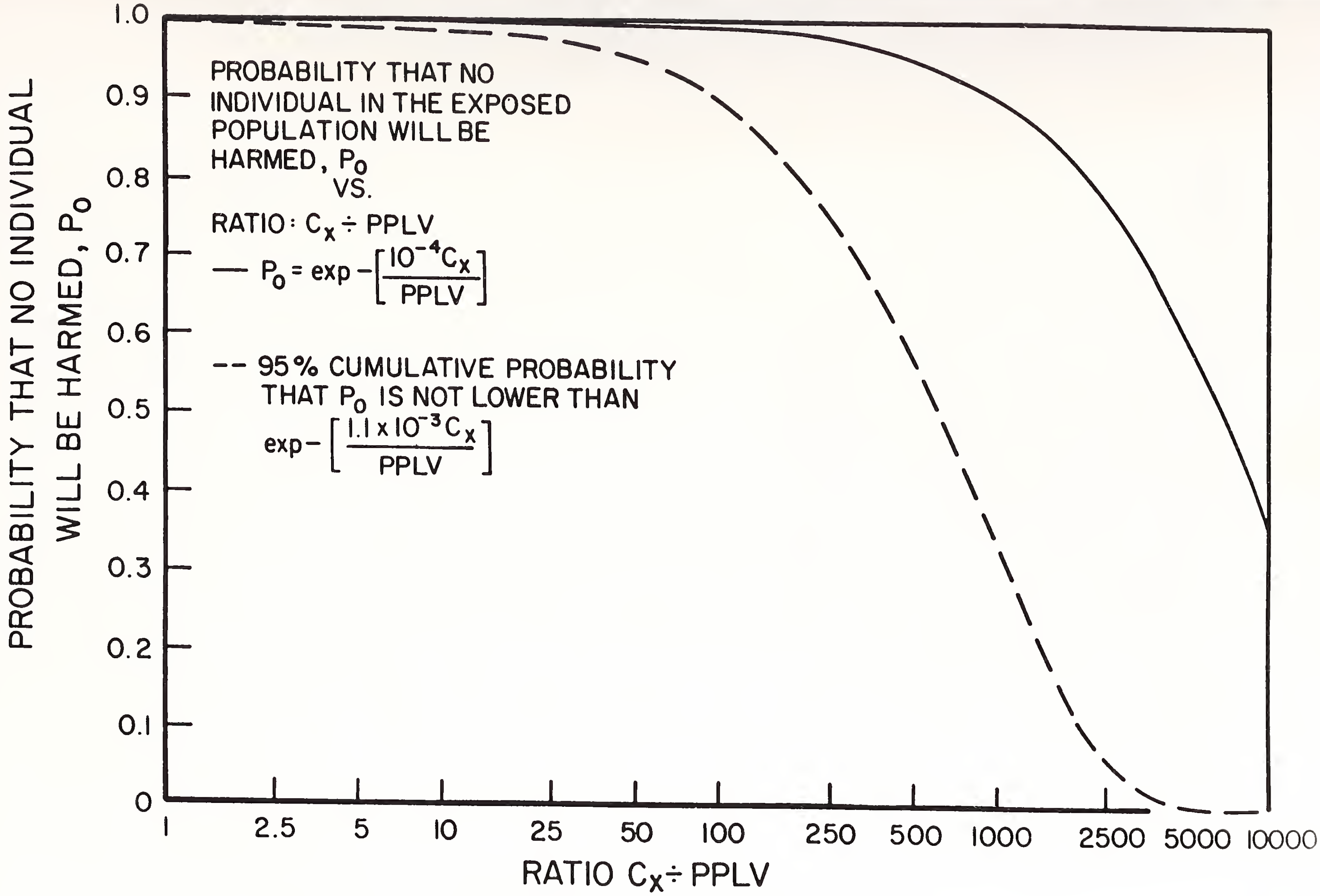


Figure XIV.8. Upper bound of 95% confidence limit (see figure 7) for P_o.

APPENDIX XV. CHARACTERIZATION OF MILLSCALE STEEL WASTES

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Preface

The American Iron and Steel Institute (AISI) requested the assistance of expertise at the National Bureau of Standards in cooperating on the problem of reprocessing of millscale and millscale sludge. Hence, the purpose of this study is to investigate the appropriate chemistry to remove the oils and greases (hydrocarbons) from the millscale waste so that an iron-rich material can be recycled into the steelmaking process. The emphasis will be on the determination of the physical properties of the millscale and hydrocarbon oil, which will affect the extraction chemistry, and not on the identification and precise determination of a few compounds. Comparison of unused grease and the oil extracted from the millscale will be sought with a view toward interpreting the changes in chemistry as they relate to steel processing.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this report to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

I. Introduction

The manufacture of steel products into slabs, sheets, blooms, billets, or bars requires that they be worked or formed in a hot strip-rolling process. During the working or forming, these products undergo oxidation, cooling, and washing with a high pressure water spray. The hot steel surface is exposed to both oxygen from the air and wash water. As a result of the exposure, layers of iron oxides formed on the surface are flaked off. As the steel product is rolled into the desired form, one layer of scale is broken off and is replaced by a new layer. A new scale is generated everytime the steel product is shaped or rolled. During the rolling process, the scale falls through the roll tables into a trough or sewer through which rapidly-flowing water is passing. A large amount of oils and greases enter and are used to lubricate the roll tables and shaping equipment. The scale, water, oil, and grease combine to form a steel waste of heterogeneous particle size. The easily filtered, large particle material (about 1 mm to 1 cm) is referred to as mill-scale. A mill-scale sludge is also generated by sand filtration of the waste water and has a smaller particle size (about 1 μm to 1 mm). Past practice has been to dispose of the mill-scale and sludge in land fill operations at the plant site. The sludge required special treatment such as dumping into lagoons or ponds. Filtering of some of the solids was often necessary as well as special treatment of the leachate. In certain cases, blending of the sludge with inert slag materials was required prior to the landfill operation.

Since the mill-scale is approximately 70 percent iron, and the sludge is approximately 30 percent iron, economic considerations suggest recovery of these metal units. However, difficulties arise when these wastes are used directly as feed stock in the sintering process because of the hydrocarbon impurities acquired from the lubricants in the hot rolling process. The hydrocarbon on the millscale is between 0.3 and 10 percent oil by weight and as much as 50 percent oil by weight of the sludge. The hydrocarbon on the scale interferes with the sintering process of preparing ore for the blast furnace. Sintering involves a careful mixing of iron ore with limestone and coal, followed by firing at red heat in a reducing gas atmosphere. The resulting coarse mix is bound together by calcium ferrite and can be fed directly into the blast furnace. Difficulties arise when the oily millscale is used as a feed because the hydrocarbon residue of the heavy grease is not burned in the sintering process, but is volatilized. When the waste air and gas is filtered with an electrostatic precipitator, the filter bags get clogged with hydrocarbon residues and can catch fire. In some instances, explosions have occurred when volatilized hydrocarbons and air reach certain mixed proportions in the electrostatic precipitator.

Disposal costs for both mill-scale and sludge are likely to increase as the regulations for waste disposal established through the Resource Conservation and Recovery Act (RCRA) are implemented. Some estimates suggest that these costs could possibly approach $50 per ton of waste. Recent figures place the annual levels of mill-scale and sludge generation by the U. S. steel industry at about three million tons per year (or 8000 tons per day).

A field trip to the Bethlehem Steel Corporation facility at Bethlehem, Pennsylvania was made by E. S. Domalski, J. A. Norris, W. A. MacCrehan, and Y. B. Tewari on Friday, February 5, 1982 to obtain a clearer understanding of the steelwaste problem from actual observation of mill-scale generation by a hot rolling steel process. The rolling or working of an I-beam (about 150 ft. in length) was observed in which layers of iron oxides were flaked off during the rolling process by the mechanical action of the mill and cooling water. About 2.5 percent of the metal units are lost in this hot-rolling process.

Millscale samples were received from the Bethlehem Steel Corp., Inland Steel Corp., and Republic Steel Corp. for study in this project. The Bethlehem Steel Corp. also provided three samples of hydrocarbon lubricants so that specimens would be available for testing as they are (i.e., unused) prior to their application to roll tables or shaping equipment.

After having examined the available information on the recovery of metal units from millscale, the following project goals were selected: (1) to establish the particle size distribution of the millscale samples, (2) to determine their hydrocarbon content by at least two methods, (3) to identify the general nature of the hydrocarbon oil (i.e., aliphatic vs. aromatic) and to indicate, when possible, any changes in the hydrocarbon lubricants by comparison to lubricants prior to their use, (4) to study the efficiency of different solvents with respect to the solubilization and extraction of hydrocarbon oil from the millscale, and (5) to determine the temperature range over which volatilization of the hydrocarbon lubricants occurs.

II. Particle Size Distrubution Study

The particle size distribution of millscale obtained from three steel industry sources was determined by gravimetrically analyzing the fractions initially obtained by sieving. Table I contains a listing of the particle size distribution of oily millscale (as received), whereas in Table II the particle size distribution of deoiled millscale (using a solvent extraction method) is listed. The distribution listed in Table II shows that nearly 30 percent of millscale consists of very fine particle sizes (-50 mesh size).

Table I. Particle Size Distribution of Millscale (as received).

Screen Size	Bethlehem weight fraction	Inland[a] weight fraction	Republic weight fraction
+10 mesh[b]	0.30_7	0.20_7	0.17_9
-10 + 20 mesh	0.18_5	0.34_3	0.20_3
-20 + 30 mesh	0.08_5	0.33_5	0.09_3
-30 + 40 mesh	0.07_6	0.05_9	0.10_8
-40 + 50 mesh	0.13_7	0.04_2	0.12_8
-50 mesh	0.20_6	0.00_9	0.28_6

---

[a] Millscale was very oily (wet) and difficult to sieve.

Table II. Particle Size Distribution of Deoiled Millscale.

Screen Size	Bethlehem weight fraction	Inland weight fraction	Republic weight fraction
+10 mesh[b]	0.26_1	0.13_7	0.15_1
-10 + 20 mesh	0.19_5	0.29_0	0.19_2
-20 + 30 mesh	0.09_1	0.11_5	0.12_0
-30 + 40 mesh	0.06_9	0.08_4	0.10_0
-40 + 50 mesh	0.08_7	0.10_1	0.13_2
-50 mesh	0.29_7	0.27_4	0.30_4

---

[b] 10 mesh = 1.7×10^{-3} meter

50 mesh = 0.29×10^{-3} meter

The Bethlehem Steel and Republic Steel samples were qualitatively similar in particle size distribution when examined as-received. The Inland Steel sample was oily (wet), and this condition apparently caused sufficient small particle agglomeration to skew the particle size distribution as compared to the other samples. However, after deoiling of this sample by solvent extraction, results for all three samples yield a similar particle size distribution, especially at smaller particle sizes. The figures listed in Table II are indicative of the true solids distribution once the binding effects of the oils have been removed.

III. Extraction of Hydrocarbon Oil from Millscale

Sampling

A single five gallon[1] can of millscale from Inland Steel was used for all of the following tests. Preliminary observations indicated extreme problems with sample heterogeneity. Because of this heterogeneity, the entire contents of the can were subjected to a repetitive quartering process (cone and quarter) until two dozen replicate samples of approximately three hundred grams each were produced. The quartered samples appeared to be homogeneous, but, within 24 hours, signs of segregation were visible within the 24 sample jars. Therefore, either the entire bottle was used for testing or the bottle was thoroughly mixed before taking subsamples.

Ignition

The initial tests on these blended samples were designed to determine the total amount of volatile residue actually present. For these tests, a tube furnace was used to heat the samples in a flowing nitrogen stream which kept oxygen and water away from the sample. At low temperatures, the condensate at the outlet of the tube furnace appeared to be water but upon attaining 200 °C the odor of some volatile material was quite apparent; at 250 °C the sample generated a white smoke. Arbitrarily, 500 °C was chosen for the sample ignition temperature, because no volatiles were detected in the N_2 gas stream and because the ignitions produced reproducible results.

A number of samples from different bottles were ignited to 500 °C for one hour under N_2 gas. The average sample size was about 15 g and the average loss on ignition was 2.07 wt. percent. The precision of these measurements was 0.15 percent, relative standard deviation (RSD). However, in this ignition experiment, all volatiles are measured, and therefore a separate determination of water by the Karl-Fischer titration was performed by S. Margolis of the Organic Analytical Research Division. One disadvantage of this method is that water which is occluded or bound as water of crystallization is not likely to be titrated. We believe that, in this case, all of the water present was adsorbed and hence titratable. In addition, because of the sensitivity of the measuring instrument, only small (∿100 mg) samples could be used for analysis. This size restriction created an additional problem since the bulk sample was originally very heterogeneous. The average value found for the water content was 0.72 wt. percent which in turn indicates, by difference, that the average amount of volatile oil present was ∿1.35 wt. percent.

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[1] 1 U.S. gallon = 3.78533 liters

Extraction

To test the relative efficiency of the extraction power of various solvents, a Soxhlet extraction apparatus was used; a 300 g sample size was chosen in an effort to minimize the effects of sample heterogeneity. The purpose of these extractions was to measure the weight loss of the samples after 2, 6, and 18 extractions for each of the four solvents tested. To do this, the experiment was stopped after the requisite number of extractions, and the sample was drained of excess solvent before removing the sample from the apparatus. The remaining solvent was removed by vacuum drying at room temperature. The sample was then re-equilibrated at room temperature and humidity before weighing. We assumed that the most volatile components, which could be lost upon vacuum drying, were actually extracted before the first vacuum drying.

The concentration of volatiles was calculated directly from the weight loss on extraction. As a second means of deducing the concentration of volatiles extracted, a small (10 g) sample was removed after each extraction experiment and subjected to the one hour tube furnace ignition. The sum of the loss on extraction and the residual volatiles should equal 2.07 percent. The solvent complicated matters since it was not possible to know when the procedure for removing solvent (drying) from the sample did not also remove water or other volatiles. The removal of excess solvent was necessary in order to determine the amount of oil extracted from the sample.

The results obtained from the extractions and ignitions are tabulated in Table III. Freon 114 (1,2-dichlorotetrafluoroethane) was definitely less effective than the other solvents. To some degree this effect may be attributed to its lower boiling point. Extraction temperatures in the Soxhlet were lower than the boiling points of the solvents, but the extreme difference in temperatures may well account for the inefficient extractions with Freon 114. Interestingly enough, all solvents yield approximately the same ultimate degree of extraction efficiency. The efficiency differences between hexane, methyl isobutyl ketone, and methyl ethyl ketone are less than the estimated experimental errors.

Table III. Apparent Extraction Efficiencies (wt. percent).

Solvent	Hexane	Methyl Isobutyl Ketone	Methyl Ethyl Ketone	Freon 114
2 Extractions	1.5_7	1.5_0	1.4_8	0.9_0
Ignition	0.4_6	0.4_9	0.5_9	1.1_7
TOTAL	2.02	1.99	2.07	2.07
6 Extractions	1.7_6	1.6_8	1.6_6	1.2_6
Ignition	0.4_3	0.5_1	0.5_7	0.8_6
TOTAL	2.19	2.18	2.23	2.12
18 Extractions	1.7_3	1.6_7	1.6_6	1.4_7
Ignition	0.3_8	0.5_2	0.5_6	0.6_1
TOTAL	2.11	2.19	2.22	2.08

Total estimated volatiles 2.07%, including 0.72% H_2O.

Also, of potential interest is the behavior of the dry (ignited) steel samples. All of these samples exhibited an affinity for water and had an average gain of 0.04 percent on exposure to air. Vacuum drying removed this water as well as solvent (and presumably volatile oils) so that exposure to the atmosphere after drying was used to preserve a consistent basis for a sequence of weight measurements. One sample was ignited to 1000 °C under N_2, and it exhibited a further loss of 0.48 percent compared to the ignition at 500 °C. This step caused visible alteration in the sample (such as partial fusion); and thus, it is difficult to know in detail what processes took place. Some inorganics are volatile at this temperature while few, if any are volatile at 500 °C. In addition, since no odorous emissions were detected or visible emissions observed during the temperature programming from 500 to 1000 °C, most of the volatile organics are probably lost in the 20 to 500 °C temperature range.

The total weight loss of these samples, whether by ignition to 500 °C or by separated extraction and then ignition is about 2.1 percent. It is likely that at least part of the 0.7 percent water in the samples is extracted by the solvents and equally likely that part of the oil fraction is not estimated. It is significant that by whatever path used, figures of ~2.1 percent total volatiles and extractables are obtained. For this extraction procedure, Freon 114 was the least efficient solvent while the others chosen for testing were quite similar in performance.

IV. Oil Recovery

The objective of the solvent study was to compare the efficiency of different solvents for the extraction of oil from millscale. Solvents of different polarity were chosen ranging from methyl ethyl ketone (the most polar), methyl isobutyl ketone, Freon 114, to hexane (least polar). Also a solid extractant, Rohm and Haas Amberlite XAD-2 (a polystyrene/divinylbenzene copolymer), was used as a model for solid phase oil recovery.

The millscale solvent extracts from a Soxhlet apparatus were taken for rotary evaporation and analysis. For the solid extraction sample, XAD-2 was mixed with the millscale in a ratio of 1:10, and the mixture was heated at 100 °C for 1 hour while being shaken. The XAD-2 was then separated by floatation on water, collected, dried, and then extracted with methyl ethyl ketone. The resulting extract was then handled in the same manner as the Soxhlet extracts. In each case, the solvents were removed by rotary evaporation under vacuum at 50 °C. The resulting "millscale extracts" from each solvent and XAD-2 were then weighed. The results were as listed in Table IV.

Table IV. Apparent Mass of Millscale Extracts.

Solvent	Grams Oil Extracted per 300 g Sample	Percent Oil Extracted
Methyl isobutyl ketone	2.34	0.78
Freon 114	2.11	0.70
Methyl ethyl ketone	1.88	0.63
Hexane	1.65	0.55
XAD-2	0.19	0.063

Few inferences may be drawn concerning the recovery of oil (by mass) as considered from the viewpoint of the effect of solvent polarity. The moderately polar solvent methyl isobutyl ketone provided the best recovery of oil by weight. However, Freon 114 (a relatively nonpolar solvent) ranked second in extraction efficiency, followed by the most polar solvent (methyl ethyl ketone), and finally the poorest efficiency was found using hexane. Differences between these results and the previously reported gravimetric results for the extractions may have been caused by loss of very volatile hydrocarbons and water during rotary evaporation.

These results would lead us to conclude that a moderately polar solvent is best for de-oiling mill scale. Thus, solvents with polarities between that of methyl isobutyl ketone and Freon 114 should provide satisfactory oil recovery. However, this conclusion must be tempered with the realization that many other parameters, besides the polarity of the solvent, must be considered in the extraction efficiency. The boiling point of the solvent comes into play since it determines the temperature of the Soxhlet extraction. Other properties such as solvent viscosity may determine the rate at which the solvent can diffuse into the mill scale particles.

The oil recovery achieved by using XAD-2 (the solid polystyrene adsorbent) was fairly low. However, this experiment demonstrated that at least some oil could be recovered by a solid adsorbent and perhaps more oil could be recovered if higher temperatures than 100 °C were used. XAD-2 is too expensive ($6/lb.) to use for de-oiling millscale, but other solids such as dry wood chips or charcoal might be more cost-effective.

V. Gel Permeation Chromatography

Gel permeation chromatography (GPC) was used to provide information about the molecular weight fractions of the mill scale extracts. This approach employs a high pressure pump which forces the solvent through a packed bed consisting of a polymer gel with a controlled, uniform pore size. In this work, a polystyrene column with a 200 Å[2] pore size was used with toluene as the flowing solvent. The solvent and polymer gel must possess similar polarities because the separation is based on a purely physical separation - diffusion. The sample molecules are forced along with the flowing solvent, but are also diffusing in and out of the gel. Molecules that are smaller than the pore size can diffuse into the stagnant solvent of the gel. Larger molecules will not so diffuse and thus will be carried more rapidly by the flowing solvent. Large molecules will elute from the column first followed by progressively smaller molecules. Although the separation mechanism is based on molecular size, this quantity is linearly related to the molecular weight for compounds of a homologous series.

The GPC system can be calibrated with a series of standards of known molecular weight, and the log of the retention volume or time can then be plotted against the molecular weight. A straight line curve was obtained for a series of n-alkanes. Several standards for aromatic compounds were also tested in order to determine their respective retention characteristics; results are reported in Table V. Aromatic compounds (benzene, perylene, and the polystyrene standards) have much smaller size (and hence, longer retention times) relative to the alkanes for an equivalent molecular weight.

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[2] Angstrom (Å) = 1 x 10^{-10} meter

Table V. Retention of Molecular Weight Standards.

Compound	Class	Molecular Weight	Retention Time (minutes)
Pentane (C_5)	n-alkane	72	3.325
Heptane (C_7)	n-alkane	100	3.175
Decane (C_{10})	n-alkane	142	3.000
Tetradecane (C_{14})	n-alkane	198	2.900
Hexadecane (C_{16})	n-alkane	226	2.775
Benzene	aromatic	102	4.45
Perylene	aromatic	252	4.20
Polystyrene Standards			
PS-1	aromatic	800	2.75
PS-3	aromatic	4,000	2.35
PS-6	aromatic	50,000	2.25

The retention times for PS-3 and PS-6 are almost identical (2.35 versus 2.25 minutes) even though the molecular weights are 4,000 and 50,000, respectively. The structure of these two compounds is much larger than the average pore size of the column. This property causes them to be totally excluded from the pores of the gel, and thus elute at very short retention times with very little resolution between the two standards.

The detection approaches used were differential refractive index (RI) and ultraviolet absorbance (UV). The refractive index detector produces an output signal that is the difference in refractive index between the sample and the reference solvent. For this work, components with lower refractive indices than toluene (the reference) are displayed above the baseline. Compounds that have lower refractive indices include straight and branched chain alkanes. Multi-ring aromatic compounds have a higher refractive index than toluene and are displayed below the baseline. An absorbance detector was also used being set at a wavelength of 315 nm (the cut-off of the toluene solvent). This detector measures the absorbance of sample molecules so provides a selective response for aromatic compounds of moderate and high molecular weight.

The conditions for the gel permeation analysis are detailed in Table VI.

Table VI. Chromatographic Conditions.

Parameter	Value
Sample size	20 μL loop injection of 50 mg oil/1000 mg toluene
Solvent	Toluene flowing at 1.5 mL/minute
Column	Polymer Laboratories PL gel 100A (200 Å effective pore diameter), 10 μm particles, 60 x 0.77 cm
Detectors	Waters R401 differential refractometer sensitivity 4X Kratos Spectroflow 773 UV absorbance detector, wavelength 315 nm, sensitivity 0.75 AUFS

The actual chromatograms obtained from the mill scale extracts (Figures 1-5) and roller lubrication greases (Figures 6-8) are included. The molecular weight and class identifications are detailed in Figure 1, based on the response obtained for the calibration standards.

There are several characteristic features of the lubrication greases that should be noted: All have a fairly large amount of an aromatic fraction of molecular weight greater than 3500 amu. They also have a large aliphatic fraction of molecular weight around 500. There is a large quantity of material having an aromatic fraction with a molecular weight between 3500 and 300, with a maximum concentration of compounds of molecular weight 600 to 800. Finally, there is a small aliphatic fraction with molecular weights below 100.

The millscale extracts show several distinct differences from the original lubrication greases. The high molecular weight aromatic fraction (greater than 3500) is substantially diminished. The moderate molecular weight aromatics (3500 to 300) are also diminished, especially the fraction with molecular weight below 1000. The high molecular weight aliphatic fraction (at about 500 amu) is virtually the same in the extracts as in the lubrication greases. There is actually a higher proportion of low molecular weight aliphatics in the extracts than in the parent lubricants.

The respective individual solvents can be compared for their efficiency of extracting the different fractions of the millscale oil by a qualitative examination of the peak heights. Table VII summarizes the results of this comparison:

Table VII. Comparison of Extraction Efficiency of Different Solvents.

	- - Molecular Weight Fraction Recovery[a] - -			
	- - - Aromatics - - -		- Aliphatics -	
Solvent	High MW (>3500)	Moderate MW (3500-300)	High MW (<500)	Low MW (<100)
Hexane	+	+++	++	+++
Freon 114	++	+++	+++	++
Methyl isobutyl ketone	+	++	++	+++
Methyl ethyl ketone	++	+++	+++	++
XAD-2	+	+	+	+

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[a] Where best recovery is symbolized by +++.

The GPC data are a direct indication of the concentration of detectable components in different molecular weight categories. However, for the millscale extracts an additional parameter must be considered when evaluating the results given in Table VII. The mass of oil extracted will also determine the relative response for each molecular weight fraction. This effect is particularly apparent for the results obtained for methyl isobutyl ketone. The experimentally determined peak heights indicate that this solvent is not very good for extracting the first three molecular weight fractions. However, because this solvent was so efficient at removing low molecular weight aliphatic compounds (and perhaps undetected low molecular weight aromatic compounds), the other fractions are effectively diluted by these components. The most oil was recovered by methyl isobutyl ketone; and thus, some of the fractions are diluted and give correspondingly low peak responses.

Several general statements can be made about the oil removed from millscale by the various liquid solvents. The oil is depleted in the high molecular weight aromatic compounds (>3500) compared to the mill lubricants. This result could be caused by one of two distinct factors: Some of the large aromatic compounds may have been "cracked" by the high temperature milling process into smaller fragments and then lost by volatilization. The second, and perhaps more likely possibility, is that this high molecular weight fraction is not being completely removed from the mill scale by the solvents tested under the conditions chosen.

Another characteristic of the extracts is the lower proportion of low molecular weight aromatics, especially of molecular weight below about 1000. These components are significantly depleted compared to the lubricants. Since these components should be easily extracted by all the solvents, they may have been lost by volatilization in the milling process or lost during sampling, shipping, and storage.

The high molecular weight aliphatics recovered by the Soxhlet extraction are very nearly equal to what is present in the lubricants for all solvents. However, a larger amount of low molecular weight aliphatic components occurs in the extracts, especially for hexane and methyl isobutyl ketone. This observation is of particular note since some of this fraction will be volatilized in the rotary evaporation step. This significant increase, relative to the other components, is probably due to cracking of larger aliphatic components in the heat of the milling process. This fraction may be of the greatest significance to the explosion problem found when untreated millscale is used as sinter feed. These low molecular weight aliphatics, such as butane, perhaps branched pentanes, and hexanes, are quite volatile and form explosive mixtures with air even at low concentrations of vapor and may contribute significantly to the explosions observed when untreated millscale is used as sinter feed.

VI. DSC Experiments

Three lubricating greases which are commonly used in rolling mills were examined using differential scanning calorimetry (DSC) to determine their initial and peak decomposition temperatures and when possible to obtain an estimate of their calorific values. Experiments were conducted with air as the purge gas at 700 kPa (100 psig) and at a controlled heating rate of 20 °C per minute. The resulting data are shown in Figures 9, 10, and 11. These figures indicate the presence of two prominent classes of organic compounds with peak temperatures in a low (257, 275, 276 °C) range and high (472, 480, 484 °C) range. A third less prominent peak (or shoulder) appears at about 300 °C.

Lubricating greases obtained by means of de-oiling millscale samples from Bethlehem, Republic, and Inland Steel Corps. using solvent extraction procedures were examined. DSC thermograms showed peak temperatures for the initial class of organic compounds undergoing decomposition at 310, 324, 325 °C; see Figures 12, 13 and 14. Calculation of calorific values for the extracted lubricating greases from Republic and Bethlehem millscale samples yielded 5162 J/g and 4817 J/g.

The thermal stability of each of the three extracted greases measured by DSC was limited to 400 °C. Above this temperature, a rapid transition was observed which was manifested by several sharp temperature spikes in the thermogram. This phenomenon is usually associated with sample ignition or explosive decomposition. This result was not observed in the unused grease. The cause of this difference may be related to the thermal history of the greases during the rolling process which resulted in a higher molecular weight material that may be oxidized very rapidly above 400 °C.

VII. Summary and Conclusions of Experimental Results

Particle Size Studies

Considering the source and nature of millscale samples, it is not too surprising that the millscale shows evidence of considerable heterogeneity (Tables I, II). As with the Inland sample, the presence of a slight excess of oil can cause a large decrease in the apparent number of fine particles. Yet, when this sample was de-oiled by solvent extraction, the number of -50 mesh particles found was very similar to the other millscale samples.

These considerations suggest difficulty in any attempt to prepare a "representative" sample or in preparing a single large homogeneous lot of material for use as a reference standard. Indeed, later experience in handling these samples demonstrated that after the process of laboriously coning and quartering a very large sample to obtain 300 g samples, the sub samples themselves later experienced some re-segregation.

Extraction Studies

Two different procedures were developed in order to determine the amount of oil in a specially prepared set of replicate samples. In the first procedure, a simple ignition to 500 °C under nitrogen was used to determine the weight loss from the samples. Although the temperature chosen was somewhat arbitrary, we believe it to be high enough to remove most volatiles and oils. Above 500 °C, no condensate could be observed on the cold parts of the combustion apparatus. In addition, most of the DSC thermogram results (Figures 9-14) suggest that the oils are volatilized below 500 °C.

The water content of the samples was unexpectedly high (0.72 percent) and this in turn caused increased difficulty in determining the amount of oil present. The ignition yielded an average of 2.1 percent volatile with a RSD of 0.003 percent (absolute). By difference, this result suggests an oil content of ~1.35 percent with a substantial uncertainty.

The second method used four different solvents in a Soxhlet apparatus in an attempt to characterize the relative extraction efficiency of the solvents. As shown in Table III, this effort was largely unsuccessful because all of the solvents, except for Freon 114, proved to be very good solvents for these extraction studies. If the average value of 2.15 percent oil found after 18 separate extractions by the four solvents is used, and the same correction for a water content of 0.72 percent is used, an apparent oil content of 1.43 percent is found. Considering the substantial uncertainties involved, this finding is in very good agreement with the 1.35 percent figure obtained by the combustion tube method.

Oil Recovery

After the removal of solvent by rotary evaporation, the four sample extracts were weighed to yield a figure for the percentage of oil recovered from the samples (Table 10). Qualitatively, the amount of oil recovered from each solvent is similar -- yet all samples yield an assay for oil which is about one half that obtained by solvent extraction and gravimetry (~0.66 percent average vs 1.43 percent). Although there may be a procedural bias built into one or both methods, the rotary evaporation probably caused a loss of a substantial amount of oil through volatilization.

Gel Permeation Chromatography

All of the extracted oil residues (as described above) were analyzed by gel permeation liquid chromatography together with samples of typical lubricants (e.g., Veedol). A comparison of the results, as illustrated in Figures 1-8, demonstrates that all of the solvents used gave good recovery of moderate molecular weight aromatics as well as all aliphatics. High molecular weight aromatics were not well extracted, presumably due to the relatively low temperature of the Soxhlet extraction.

The relative proportions of low molecular weight aromatics are depleted in the extracts relative to the lubricants whereas the relative proportions of the low molecular weight aliphatics are increased. No clear explanation for this difference was found.

DSC Experiments

The results of these experiments are illustrated as DSC thermograms in Figures 9-14 and may be summarized as follows: Two prominent peaks were found for the unused lubricating greases, and these peaks correlate well with the gel permeation-liquid chromatography studies of the same materials. Peak decomposition temperatures between 470-485 °C for unused lubricating oil may correspond to the high molecular weight formation observed by gel permeation-liquid chromatography. The 500 °C temperature used for the combustion tube-nitrogen sweep of the samples is well above the highest peak observed. The peak decomposition temperatures between 310-325 °C for the millscale extracts could correspond to the high molecular weight aliphatic fraction observed in the gel permeation liquid chromatography study.

Conclusions

Fairly large samples (300 g) were required to give reasonably significant data for the comparison of the relative extraction efficiencies of four solvents. Since all of the solvents except

Freon 114 exhibited high efficiency, the chances are good that a less costly and more environmentally acceptable solvent than Freon 114 can be found. Experiments such as these may prove useful in studying and optimizing operational millscale deoiling operations. The very simple measurement of loss on heating to 500 °C (under N_2) may prove to be a useful method for measuring the efficiency of deoiling plants. The method is quick (1 hour), precise (>>1 percent relative), consumes little sample (15 g), but does require a correction for the water content of the sample.

APPENDIX

Description of a Deoiling Plant

I. Selection of a Process and Solvent

Several methods of deoiling of steelwaste have been investigated and are described in the literature [1]. These may be classified into three groups:

1) Thermal incineration
2) Saponification and solution in large quantities of water
3) Washing with organic solvent

The incineration method is high in energy consumption. Also, it creates a secondary exhaust control problem with additional energy requirements, and a tertiary waste water problem. (Such an installation can scarcely be constructed without a gas scrubber.)

The heating of one ton of scale to 600 °C (red heat) consumes about 110 kWh as thermal energy. The fuel consumption of a rotary kiln installation with flue gas afterburner and wet scrubber, working in the USA, is reported to be 261 kWh/t scale.

Washing with detergents to remove oil is also judged to be unfavorable and expensive as the costs for detergents are intolerably high especially when combined with the cost of treating the resultant waste water. The latter task stretches prevailing legal tolerances. It seems absurd to convert a disposal problem, with much effort, into a waste water problem.

Only the process of deoiling of millscale with solvents seems practical without significant effort and expense to avoid secondary pollution of the environment. The necessary process technology has been developed and utilized successfully [2] to deoil steelwaste in Europe. Freon 11 (trichlorofluoromethane was the solvent used for the extraction process. However, this solvent may not be acceptable to the U.S. Environmental Protection Agency due to its adverse environmental effects. Therefore, one wishes to select a low boiling hydrocarbon as an extracting solvent. The selection of an appropriate solvent should be based on the following criteria:

1) Favorable threshold limit value for work place atmosphere and not injurious to health.

2) Trace amount remaining in deoiled grease should be nonflammable or burn cleanly, thus to avoid explosions during sintering.

3) Chemically stable and easy to recycle.

4) Effective removal of greases and oils from the millscale.

5) Economic practicability, favorable price.

Several hydrocarbons have been examined as solvents for extraction of oil from millscale. Based on deoiling efficiency, hexane may be used as an extracting solvent. Hexane is relatively cheap and non-toxic, and trace amounts of hexane remaining in deoiled grease will burn cleanly and will not pollute the atmosphere. Unlike Freon 11 used in European Plant, hexanes are highly flammable liquids and increase the risk of fire in work place. However, U.S. food industries have been using hexane as a solvent to extract oil from grains. So the flammability problem apparently can be handled by means of the existing technology in food industries.

II. Major Features of the Plant

The plant consists of three processing units:

(A) the deoiling unit
(B) the solvent reclamation unit
(C) the exhaust air cleaning unit

III. Deoiling of Millscale

In the millscale doiling unit, adherent grease and oil are removed from the scale by the solvent Freon 11*; the scale is then washed with hot water to vaporize adherent solvent. This unit is covered by a gas and vapor-tight hood, into which a large, refrigerant-cooled condensor is incorporated.

The screened greasy scale is taken from the hopper and fed by weight into the material entrance sluice. The drawing off of scale from this entryway is regulated by means of a load cell in such a manner that a full material column will always be maintained sufficient to form a seal against the escape of solvent vapors.

Inside the subsequent double screw mixer, the greasy material is mixed with solvent in order to break up scale and sludge lumps held together by grease. The mixture then falls into the solvent bath. While the scale is sinking in free fall to to the bottom of the bath, the oils and greases are dissolved. The scale is drawn off the bottom of the solvent bath by an ascending screw conveyor, and above the bath level it is rewashed with clean solvent. As the scale is conveyed further upwards the solvent is drained from it. Still-adherent solvent remains are vaporized by means of hot water in a scavenging rinse trough which brings the scale into a hot water bath. With a dewatering screw conveyor, the scale is then moved out of the water system to the draining area, outside of the building. At the same time, the rinse trough and screw conveyor serve as a seal against the escape of solvent vapors on the discharge side.

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* Solvent Freon 11 can be replaced by hexane.

The hot process water moves in a closed circuit, losses to the scale being made up with fresh water additions. The overflow from the rinse trough is cleaned in a laminated settler and a non-clogging screen before it is returned to the sump.

The heat losses from the water due to the evaporating of residual solvent, and from the associated heating of the scale, are restored in the condensor of the refrigerating engine. Water is reheated to about 53 °C* and is then returned to the solvent scavenging rinse trough.

IV. Solvent Reclamation

The solvent utilized for the dissolving of oils and greases is completely reclaimed in a three-stage distillation plant:

The grease and oil-bearing solvent, the "miscella", flows over the brim of the solvent bath into a collecting channel leading to the miscella collecting tank. On its way, the miscella passes a magnetic filter and a non-clogging screen for filtration.

A partial flow is pumped back into the double screw mixer of the deoiling unit; the main part is charged to the solvent recovery system.

In the first distillation stage, which is constructed as a forced circulation evaporator, about 90 percent of the solvent is recovered. The miscella is preheated with hot water to 23 °C*, then heated up to 24.5 °C* under atmospheric pressure (1 atm). The required process heat is collected from the connected solvent condenser by means of a heat pump. The heat is transferred via a secondary refrigerant circuit. The pressure gradient necessary for heat recovery is induced by a turbo compressor.

The liquefied clean solvent returns to the ascending screw conveyor of the deoiling unit, above the solvent bath level, for rewashing of the scale.

From the first-stage evaporator, the concentrated liquid oil/solvent mixture is pumped into a second distillation stage, which is also constructed as a forced circulation boiler.

This stage works at 50 °C* and 1.1 atmosphere pressure. The process heat is delivered by hot water. The vaporized solvent is recondensed by refrigerant and flows also into the screw conveyor of the deoiling unit.

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* Conditions will change due to the use of hexane as solvent.

This (further) concentrated miscella flows continuously into the batch evaporators of the third distillation stage. In this stage, final solvent vaporization is effected at about 100 °C* and under vacuum. During filling of the evaporator and heating of the miscella to 100 °C* the solvent vapors are vented under normal pressure to the condenser inside the gas-tight hood covering the deoiling unit and thereby liquefied.

When filling is finished, the apparatus is set for vacuum evaporation. At first the pressure is lowered to 133 mbar* (100 mm Hg pressure), thereafter to about 27 mbar (20 mm Hg pressure)*. As soon as this pressure is reached, (at about 100 °C*) the discharge valve opens.

The oil/grease mixture obtained in this manner contains only traces of solvent, lying near the limit of analytical determination. The oil/grease mixture is delivered to the waste oil treatment plant of the steel works. The oil has a calorific value which is in the range of that of heavy fuel oil.

VI. Cleaning of Exhaust Air

As already mentioned, the deoiling unit is sealed by the feed hopper on one end and by the water bath on the other side. Gases in this range are captured in a gas hood. The solvents are mostly liquefied by means of a condenser in the hood, and are returned to the screw conveyor. The air which is brought in with the scale, saturated with solvent vapor, is drawn out and cleaned in an air cleaning installation.

The solvent-saturated air is treated in an ejector and a bubble tray column with cold absorption oil. The solvent vapors are absorbed by the oil, and the cleaned air is discharged. Regeneration of the absorption oil is effected by heating it up to 90 °C* and by expanding, first into a flash cyclone at 100 mm Hg* and then into a falling-film evaporator at 20 mm Hg pressure*.

The solvent vapors are compressed and recondensed by the vacuum pumps, and the liquified Freon 11* is recycled into the deoiling process.

Summary

Fires occurring in precipitators of modern sinter plants can be attributed to the introduction of hydrocarbons into the sinter mixture. Oil-containing scale must, therefore, be de-oiled before it is sintered if conventional technology is used. For this purpose, a process has been developed, by which oils and greases are removed from the scale by use of the solvent Freon 11; hexane can be substituted, however. The use of this solvent allows for a nearly total solvent recovery from the separated oil/grease mixture, and also permits the application of large heat pumps to the circuit.

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*Conditions will change due to the use of hexane as solvent.

A plant constructed for 50 t/h scale would have a solvent consumption of about 1 kg/t scale at an average inbound oil content of 0.4 percent. The overall energy consumption, thermal and electrical, amounts to 14 kWh/t. The residual oil content in the deoiled millscale is about 0.01 - 0.03 percent.

This deoiled millscale is usable in the sinter mix without any difficulties.

This study was funded by the NBS Office of Recycled Materials in response to the needs of the U.S. steel industry as represented by the American Iron and Steel Institute (AISI), Committee on General Research, Unit 2 - Removal of Hydrocarbons from Iron-Bearing Wastes.

References

[1] Balajee, S. R., Deoiling and Utilization of Millscale. First EPA Symposium on the Iron and Steel Pollution Abatement Technology. November 1, 1979.

[2] Barnes, T., AISI Committee Correspondence. December 29, 1981.

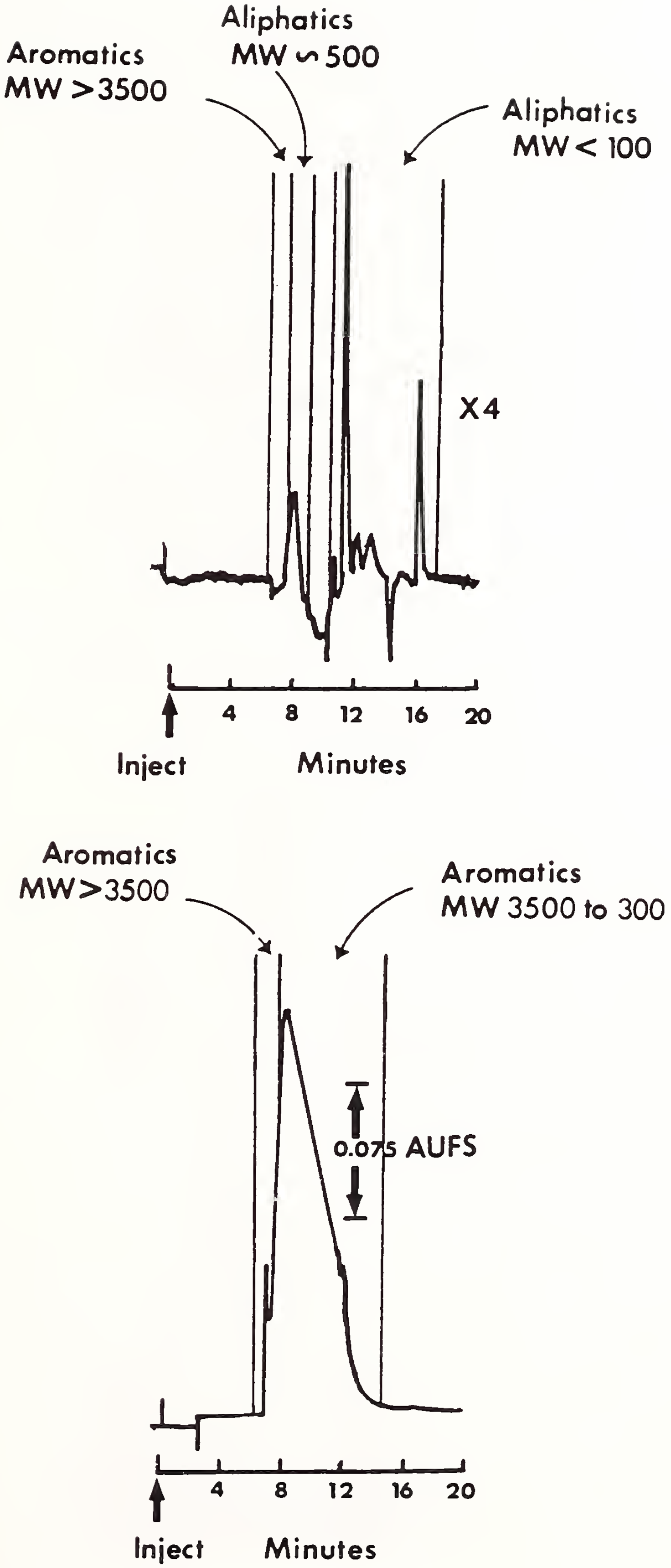


Figure XV.1. GPL chromatogram, millscale extract methyl isobutyl ketone solvent.

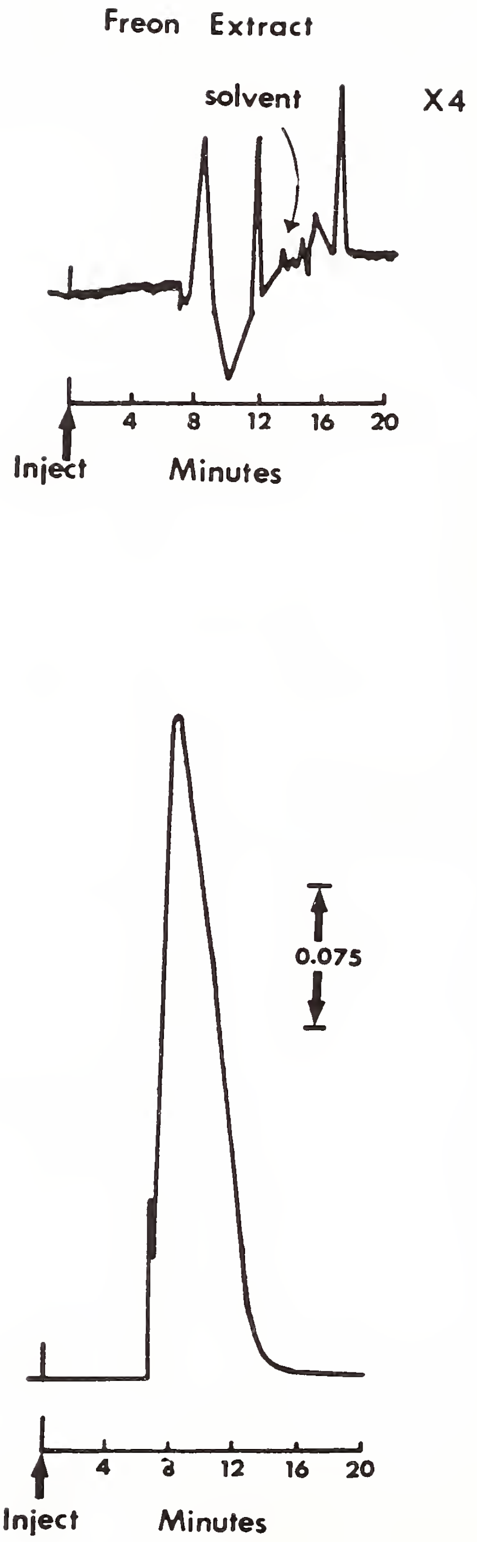


Figure XV.2. GPC chromatogram, millscale extract Freon 114 solvent.

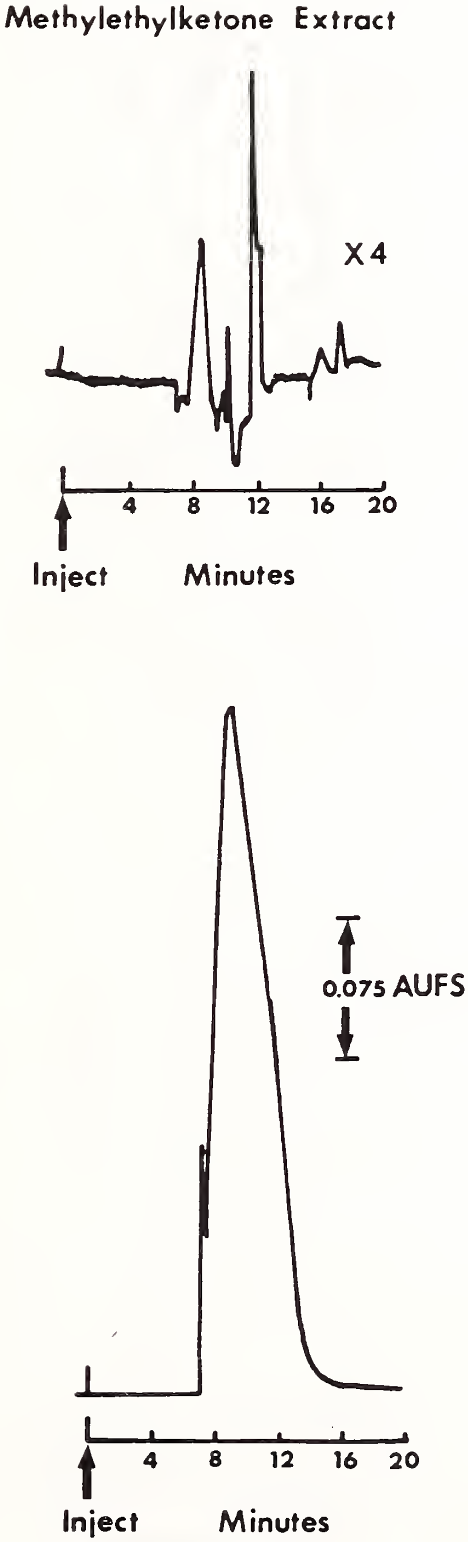


Figure XV.3. GPC chromatogram, millscale extract methyl ethyl ketone solvent.

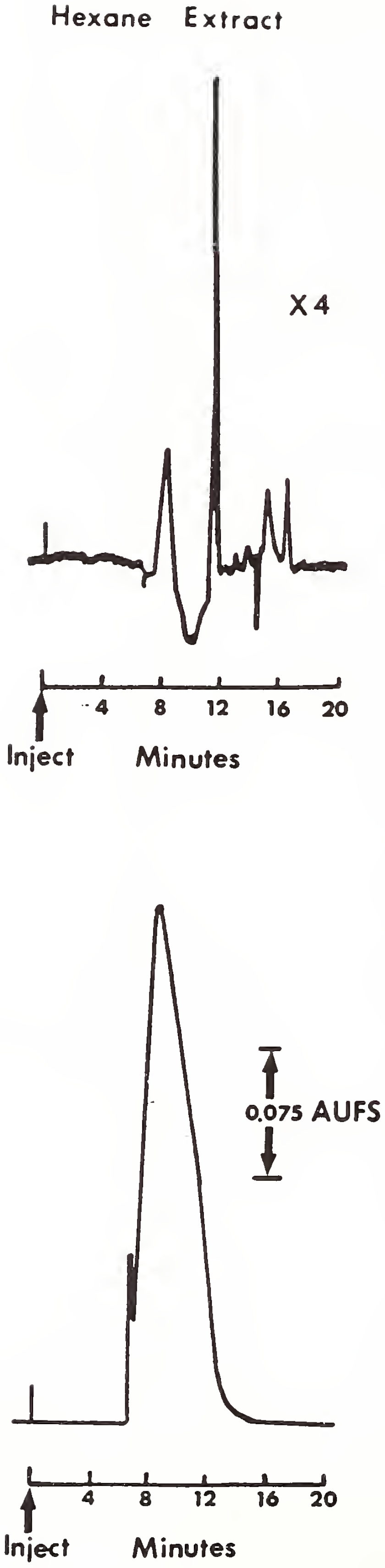
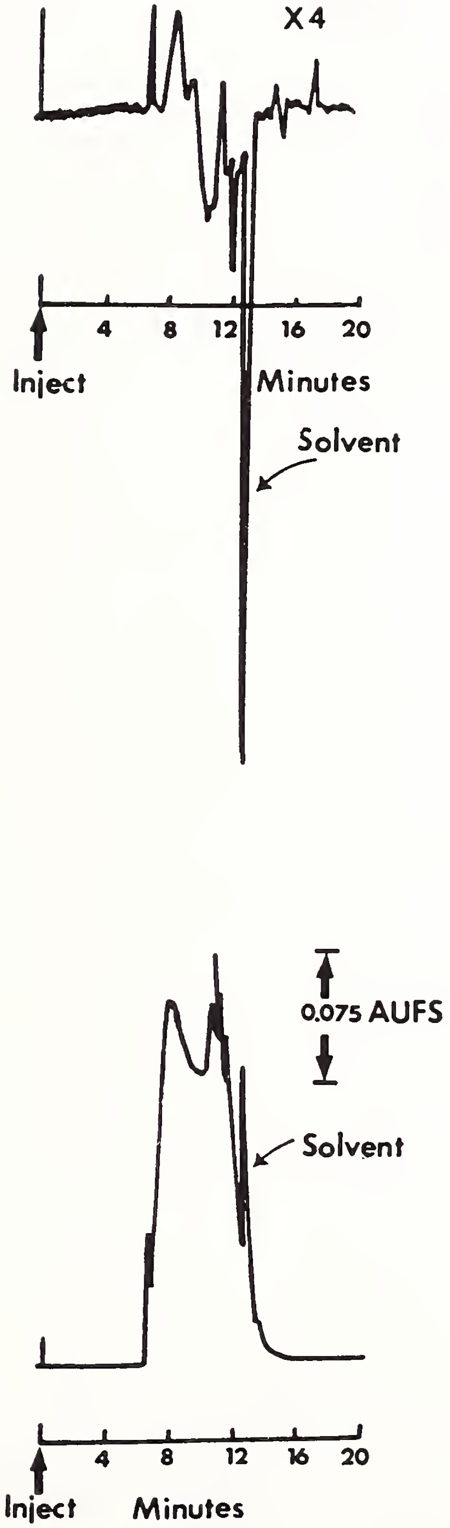


Figure XV.4. GPC chromatogram, millscale extract hexane solvent.



XAD-2 Extract

Figure XV.5. GPC chromatogram, millscale extract XAD-2 solvent.

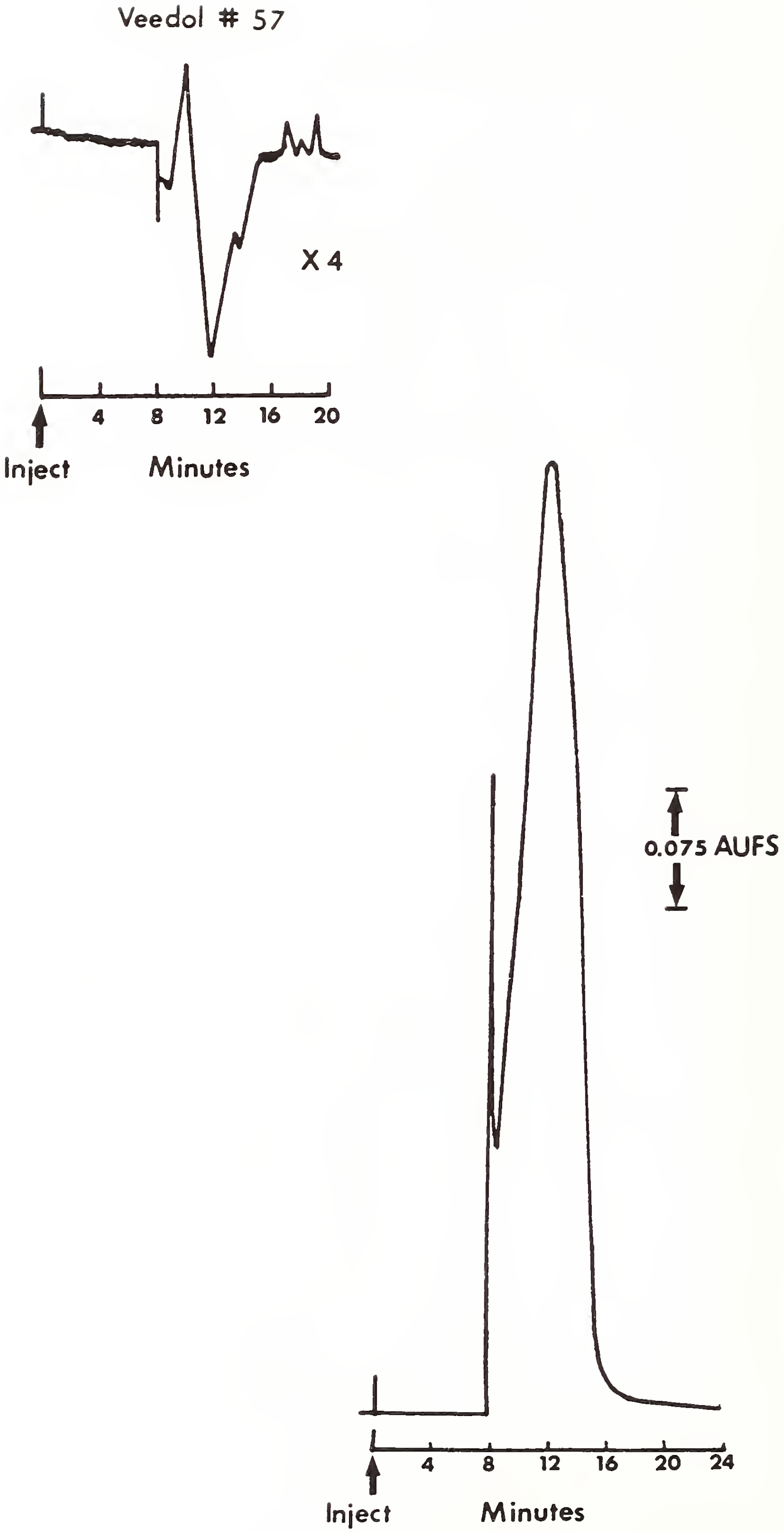


Figure XV.6. GPC chromatogram, Veedol #57 mill lubricant.

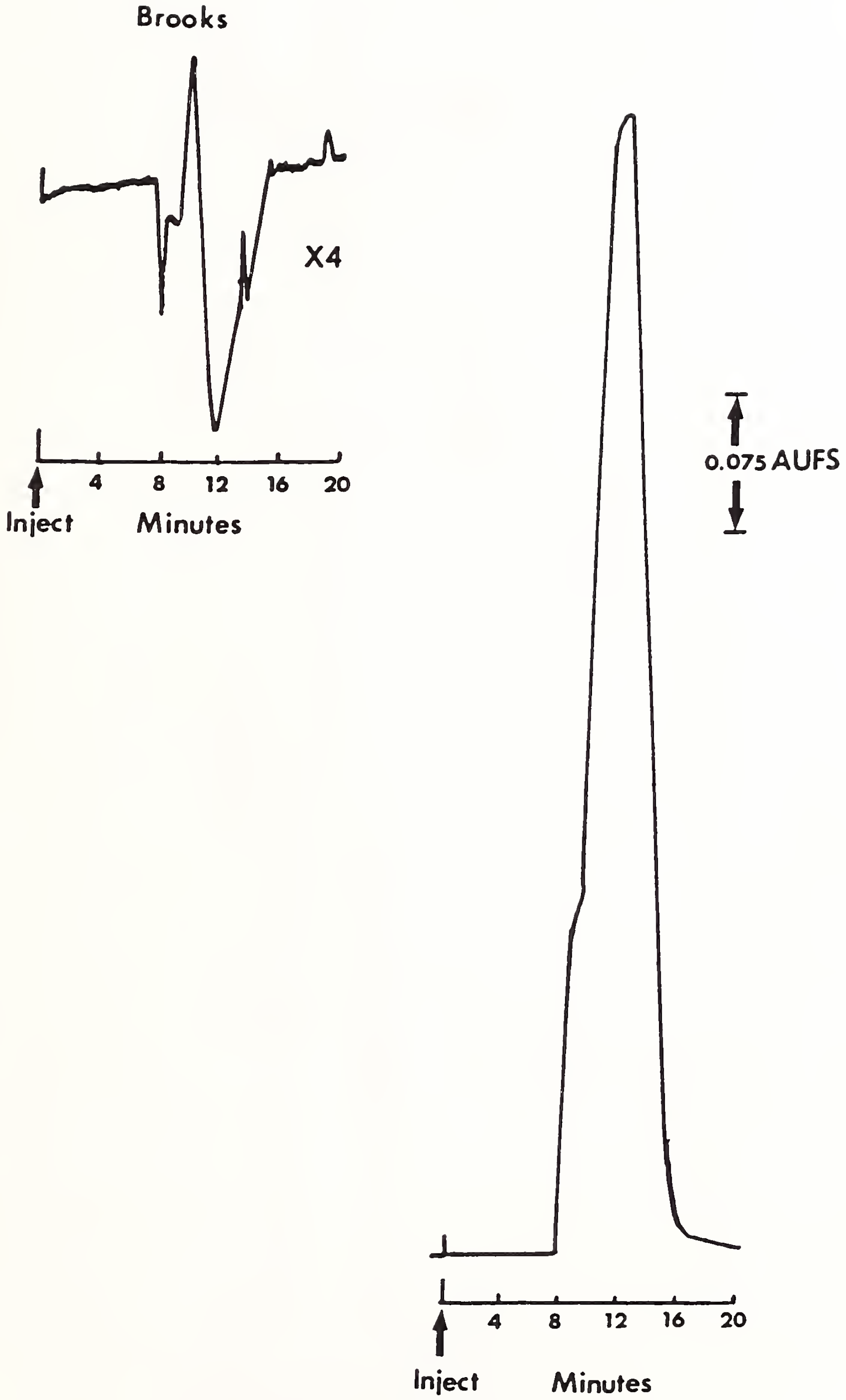


Figure XV.7. GPC chromatogram, Brooks lubricant (prior to use).

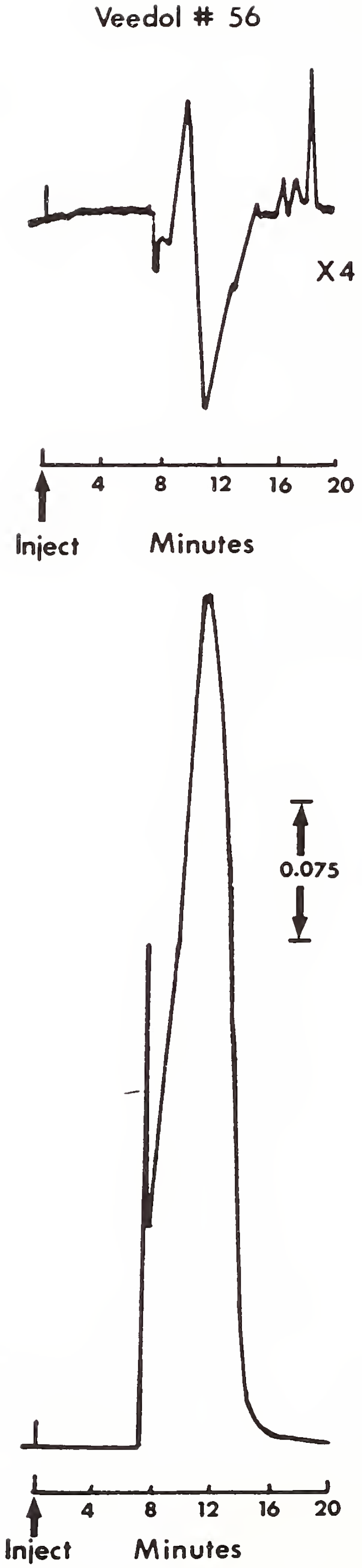


Figure XV.8. GPC chromatogram, Veedol #56 lubricant (prior to use).

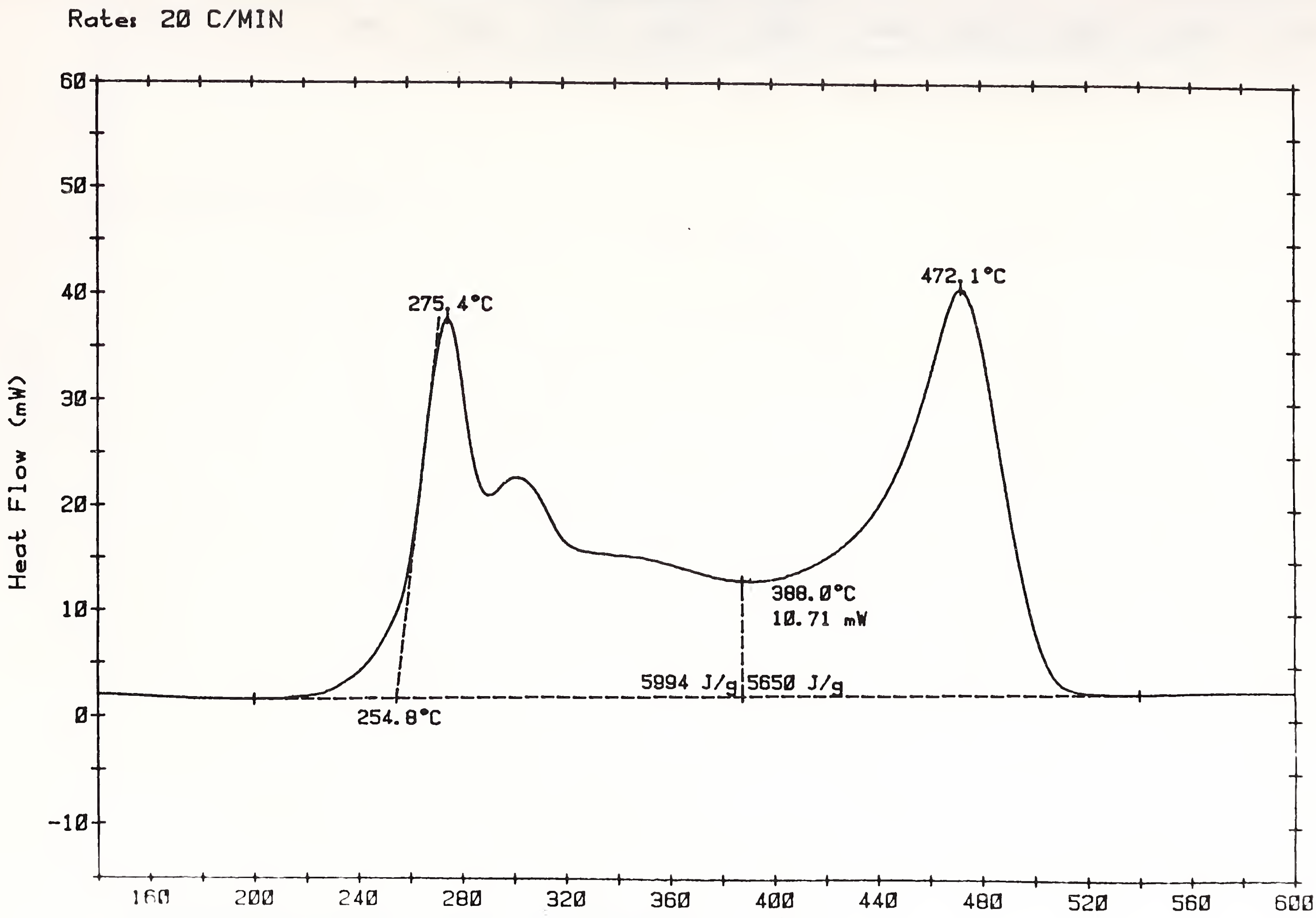


Figure XV.9. DSC thermogram, Brooks mill lubricant.

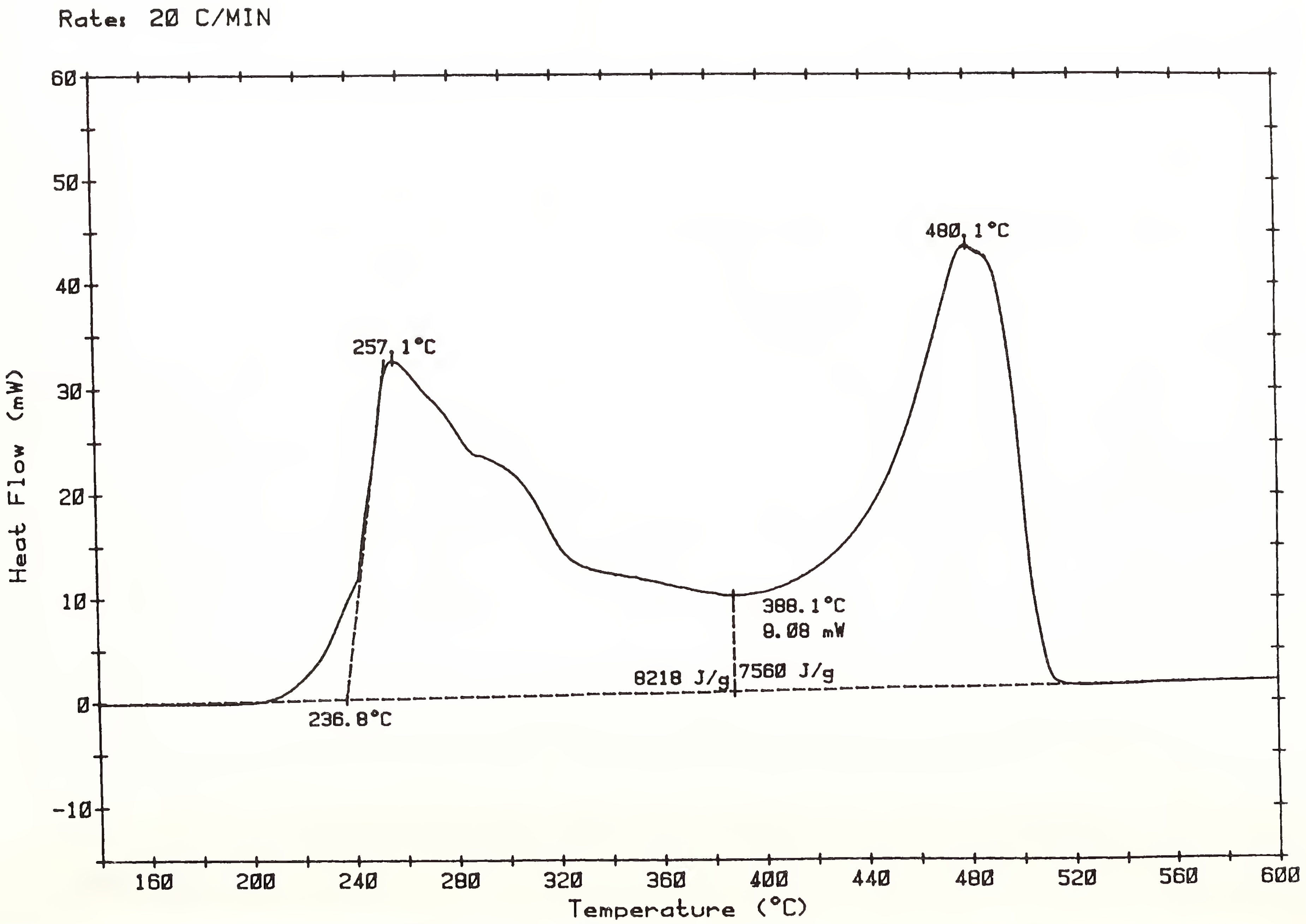


Figure XV.10. DSC thermogram, Veedol #56 mill lubricant.

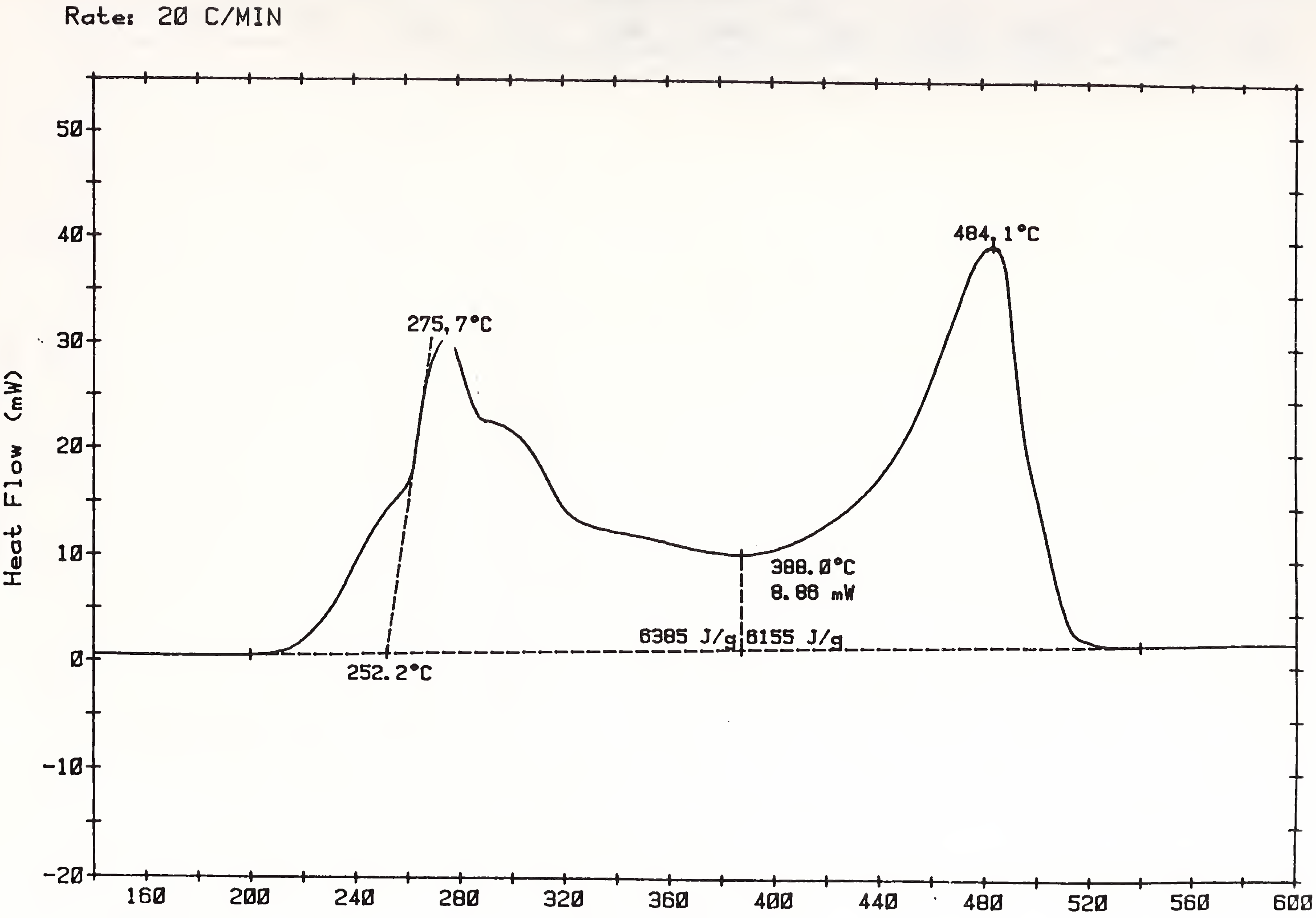


Figure XV.11. DSC thermogram, Veedol #57 mill lubricant.

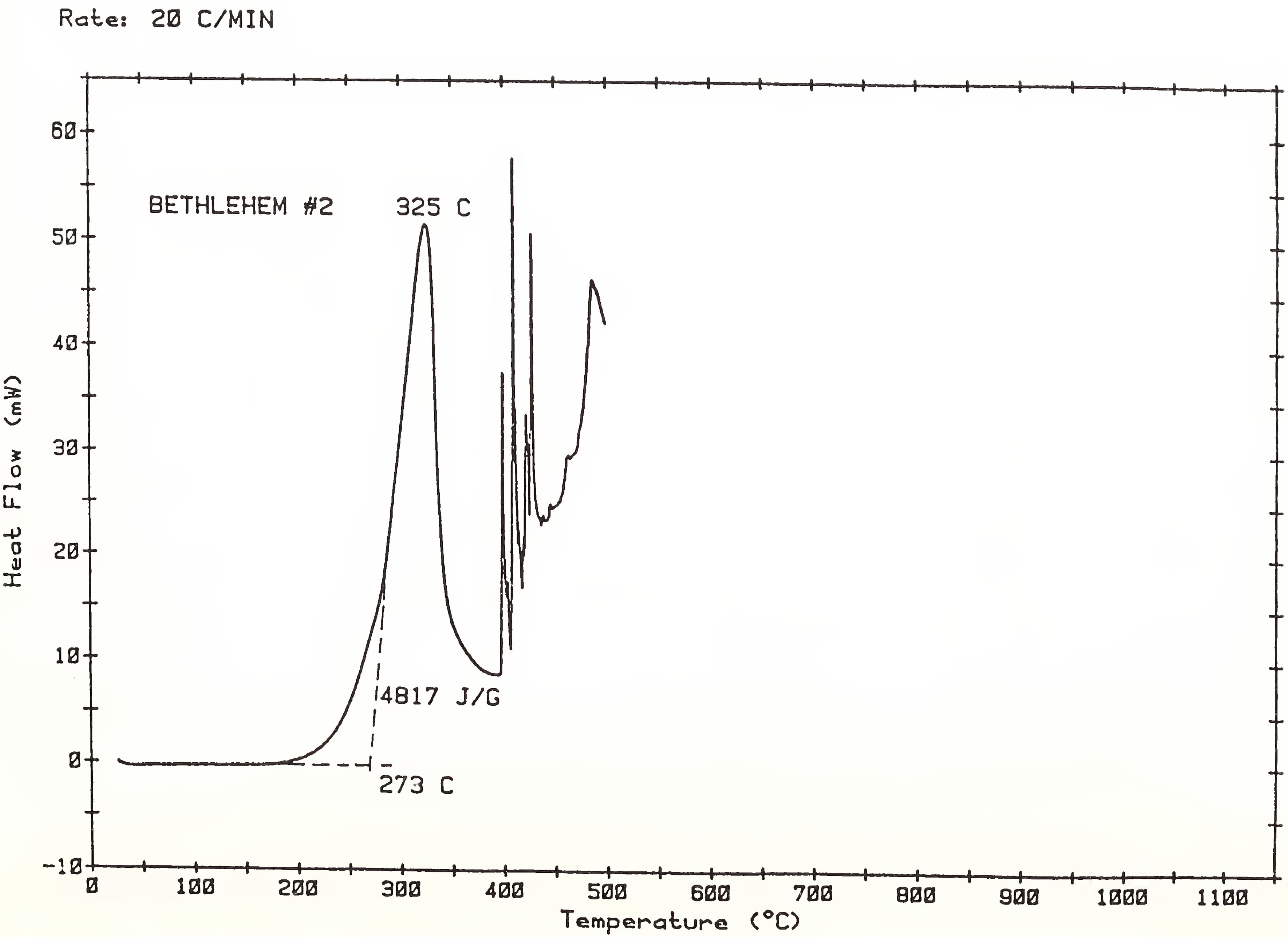


Figure XV.12. DSC thermogram, millscale extract Bethlehem #2.

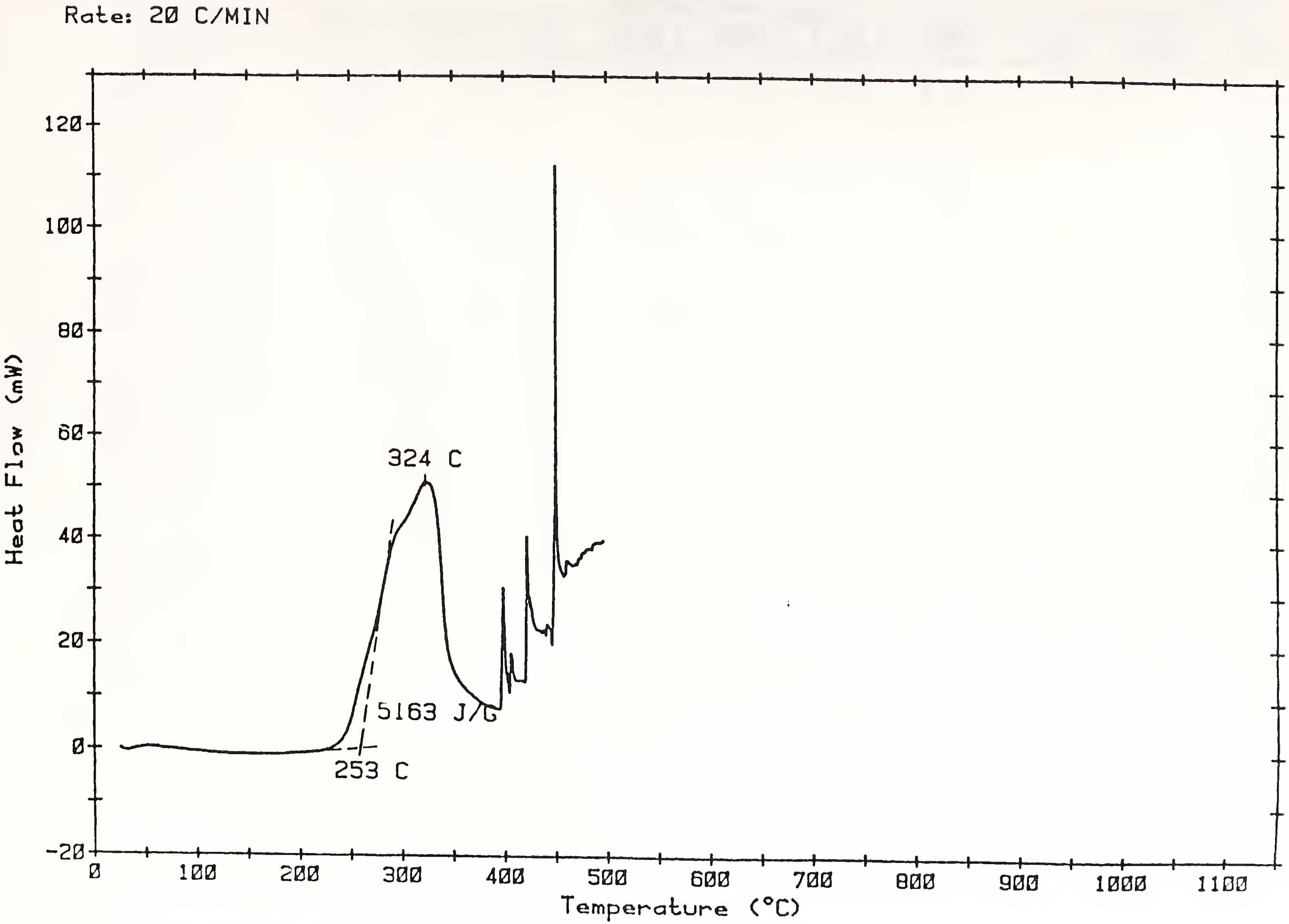


Figure XV.13. DSC thermogram, millscale extract Republic #1.

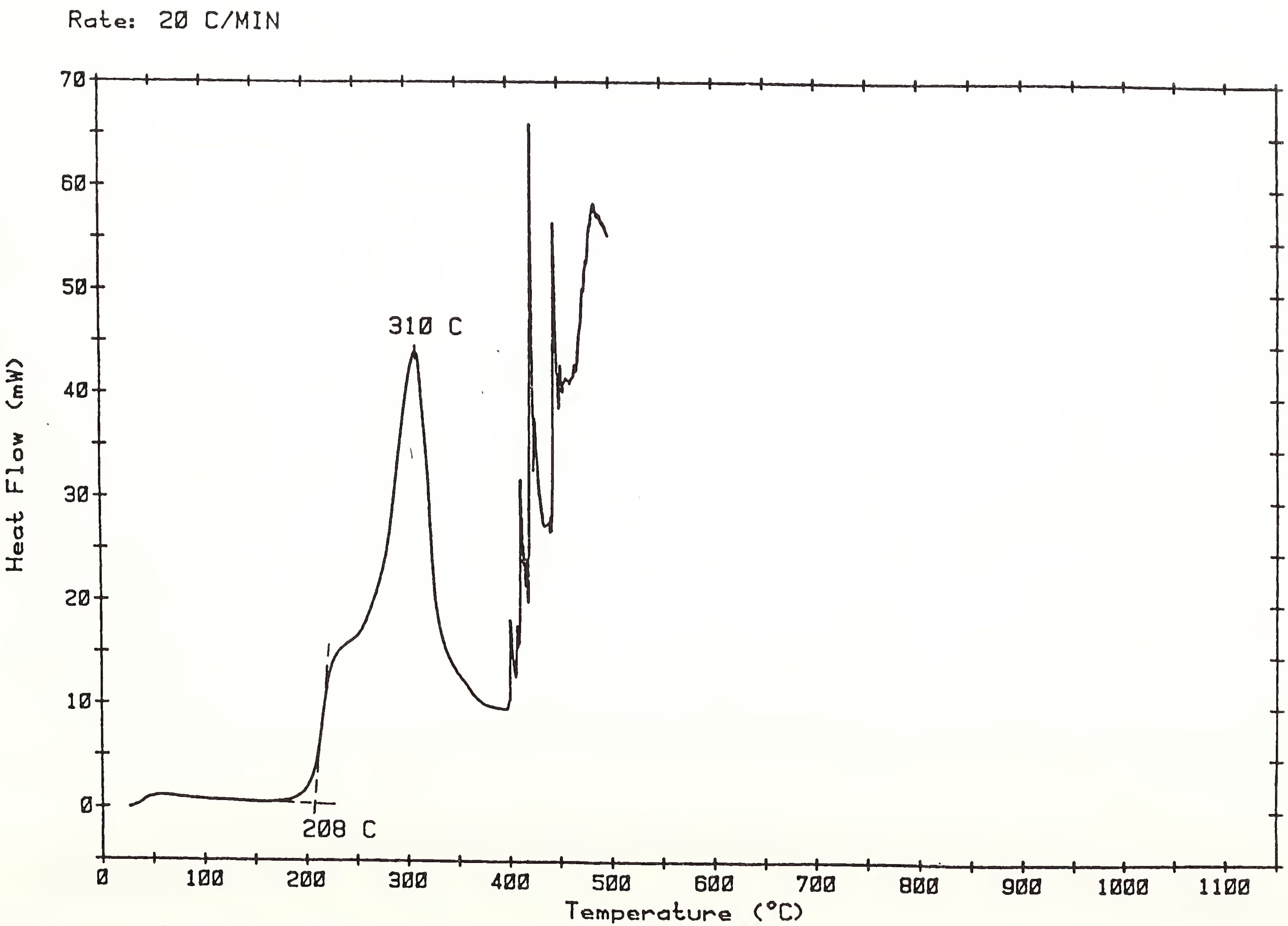


Figure XV.14. DSC thermogram, millscale extract Inland #2.

APPENDIX XVI.

Evaluating the Risks of Solid Waste Management Programs: A Suggested Approach

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Background

Solid waste management is among the most complex municipal or regional governmental tasks facing policy makers today. The physical problem of where to locate needed facilities is further complicated by the increasing costs of disposal, new technologies, environmental regulations and the unavailability of the land for landfill. The problem becomes even more challenging when one notes that solid waste management facilities may exhibit economies of scale in construction and processing. This possibility implies that the benefits associated with lower per unit processing costs can only be achieved through regionalization. However, the process of regionalization creates two fundamental problems: (1) the complexity of the regional system design; and (2) the need for political consensus. Both of these problems may be addressed by developing and clearly presenting technical and economic data about the consequences of various regional approaches. Finally, by opting for regionalization, decision makers must weigh the benefits of reduced processing costs against the risks of cost overruns which are inherent in large construction projects.

The approach outlined in this paper attempts to integrate the regional planning problem with a technique for evaluating the risks of resource recovery options. This is accomplished in two stages. First, the Resource Recovery Planning Model (RRPLAN) is described. This section of the paper summarizes the model's assumptions, major components and modes of operation. An algebraic statement of the problem is then given along with a description of the solution algorithm. The second section consists of an in-depth case study for central Mississippi. A coordinated set of questions are hypothesized and solved to illustrate how the model would be applied in an actual planning context. The model's results are then used to develop statistical relationships which permit an explicit assessment of project risk.

The Resource Recovery Planning Model (RRPLAN)

Over the past decade, there has been a proliferation of mathematical models dealing with such issues as facility location, vehicle routing and manpower planning (Liebman [1975]). Due to unrealistic data requirements or the complexity of using and interpreting the model's results, the application of these models to the solid waste management problem has sometimes been disappointing. More recent modeling approaches have attempted to couple the analytical power of the computer with the ability to organize systematically the thoughts of the decision maker so that important pieces of information are not overlooked (Jenkins [1982], Chapman and Berman [1983]). From these experiences, it is possible to define a set of criteria that any model which purports to deal with solid waste management problems should satisfy. At a minimum, any such model should be able to derive explicitly the effects of alternative financial and cost-sharing arrangements, allow for economies of scale, and be amenable to sensitivity analysis associated with a well-chosen set of "what-if" questions.

Although the general solid waste management problem poses some formidable difficulties to decision makers, the economic analysis of resource recovery options is significantly more complicated, since an in-depth analysis of facility design and cost as well as market size, structure and location is required. In order to address these complicating factors, RRPLAN deals with two interdependent issues. On the one hand, RRPLAN explicitly incorporates potential economies of scale in the construction and operation of a solid waste processing facility. The model is thus able to support the basic tradeoff of savings from centralized processing versus the costs of additional haul required to bring such savings about. On the other hand, RRPLAN uses a detailed cost accounting system to attack the economic issues by carefully estimating the effects on overall program costs due to decisions affecting siting, routing, marketing and financing. By integrating the technical issues of processing with these four major decision points, RRPLAN permits a wide variety of questions to be examined carefully.

RRPLAN may be thought of as a descendant of two earlier models. These models are known as WRAP, Waste Resource Allocation Program (Berman [1977], Hensey [1977]), and RAMP, Recovery And Market Planning (Berman [1976]). Both models were developed by the Mitre Corporation, the former through funding from the Environmental Protection Agency. There are substantial differences between the two models, especially regarding their software support systems and their treatment of market structure. Both models use the same optimizer as RRPLAN. In WRAP, as in RRPLAN, a front end is available to build the equations for input into the optimizer, and a back end is available to interpret the solution. In RAMP a more sophisticated equation structure is available, including the full market structure in RRPLAN, but the user must prepare equations for direct input into the optimizer, and must interpret its solution. The major focus of WRAP is on the identification of a preferred plan which includes the best candidate sites, the appropriate processing and disposal technology at each site, the sizing of each site and all transportation linkages among centers of waste generation, processing sites, and disposal sites. A major weakness of WRAP is its implicit assumption that any market for recoverables (e.g., ferrous products and newsprint) is unlimited. If market saturation is an important consideration, then WRAP's solution would represent an overly optimistic plan which could lead to serious cash flow problems if the plan were implemented. RAMP adds the saturation effect by incorporating both declining price and limited size markets.

RRPLAN, on the other hand, incorporates all of the capabilities of WRAP and RAMP, as well as numerous enhancements which render its cost accounting system far superior to those used in its predecessors. Furthermore, RRPLAN's more reasonable data requirements than WRAP, coupled with the type and nature of its output, should permit RRPLAN to greatly facilitate the regional planning and decision making processes. RRPLAN contains a more realistic cost model, built-in source-separation options, an automatic dedicated transfer station function, user-defined cost, energy, and commodity categories, and an extensive analysis of costs by source and site, including a projected full-cost tipping fee for each site.

RRPLAN is a computer model designed with three purposes in mind. First and foremost, is the ability to generate a preferred plan for resource recovery. Second, is the capability to evaluate a scenario specified by the decision maker for technical and economic feasibility. Third, is its use as a tool to facilitate the decision making process by providing answers to many what-if questions through an in-depth sensitivity analysis.

The model has five basic modes of optimization. Each mode serves to define the type of objective which is to be minimized or maximized. The first two modes of optimization minimize the total cost of the regional plan over a specified planning period. The first mode minimizes the discounted costs of the regional plan. Such an objective function would be required if both the timing and magnitude of cash flows are important. If only the magnitude of cash flows is important, then the second mode, minimization of undiscounted costs, should be chosen. The choice of discounted rather than undiscounted costs, or vice-versa, may cause both the costs of the plan and the physical flows within the system to differ. The first mode, minimize lifetime discounted cost, is the preferred criterion for plan selection and evaluation. The third mode of operation seeks to maximize the net energy of the regional plan (i.e., energy produced (saved) from (due to) resource recovery activities minus all other energy inputs). Such an objective function might be useful in comparing various waste-to-energy programs. The fourth mode of operation seeks to minimize a linear form (weighted sum) of program cost and net energy categories. This approach might prove useful in comparing mixtures of traditional and waste-to-energy programs if some form of matching formula for funds was in effect. This mode of optimization will permit the user to weight cost or energy categories other than equally. The fifth mode focuses on the topic of scenario evaluation. For example, a region may propose a plan which needs to be evaluated from the viewpoint of technical and economic feasibility. Typical questions addressed under this mode of operation would include the following: Are all facilities able to process the indicated waste stream without exceeding their rated capacity, or that of plants down the line into which they feed? Can resources be reallocated so that overall costs are reduced?

In order to handle the five types of objectives just discussed, RRPLAN includes a set of cost categories, energy categories, and commodities. Cost categories are the heart of RRPLAN's accounting system. They are included so that the differential impacts of the regional plan on the various segments of the population, as well as financial transfers into the region from marketing activities, can be measured. Individual cost categories are classified as either operating (i.e., recurring annual costs) or capital. Each cost category has a cost growth scenario (differential inflation rate) associated with it, so that it may increase more (or less) rapidly than the general rate of inflation. Financial arrangements are explicit in all capital cost accounting. All capital items, except those currently in use, are assumed to be purchased at the beginning of the planning period. Replacements which occur within the planning period are inflated by the differential inflation rate from the first year of the planning period to the year of replacement. A standard amortization calculation is used to generate an annual cost for each year of the capitalization of the loan. A series of cost summation categories permit the user to aggregate cost categories having differential inflation rates, useful lives, etc., into a single cost summation category for further analysis. Energy categories may be handled in a similar manner. The model greatly facilitates the process of performing a detailed cost analysis, once a solution has been found, by leaving the user ample opportunity to define the types of commodities processed and sold (e.g., municipal solid waste (MSW) and steam). The use of separate commodity categories also permits one to measure the effects of differential transportation costs (e.g., handling MSW versus newsprint) as well as cost-sharing arrangements for processing and/or revenue-sharing arrangements among municipalities for marketing activities.

The basic structure of RRPLAN consists of a set of equations and activities relating sources of solid wastes, sites where the wastes can be processed and markets for energy or recovered materials. Figure 1, a capsule summary of the major physical system details, outlines the relationship between the model's equations and activities.

Both the model and the physical system begin with a source of waste, or "waste generation zone." At this point RRPLAN permits the user to offer two types of source separation for consideration or to ship the mixed MSW directly to a processing facility. Under the first source separation scenario, the model assumes that all paper, glass and cans are removed from the waste stream, sent to a central collection point, and then shipped to the respective market. This option is referred to as unconditional source separation. Under the second source separation scenario, paper, glass and cans are always removed but paper is treated separately. As in the previous scenario, cans and glass are sent to the central collection point and marketed. Paper, on the other hand, is put to two possible uses which reflect both its fiber value in recycling and its energy value in combustion. This option is referred to as conditional source separation. The rationale behind this scenario is as follows. If the price of paper exceeds some prespecified price (up to five such "trigger" prices are available) then it will be marketed for its fiber value; otherwise the paper will be burned. If multiple options are offered at a source, the model selects the preferred option. For example, all transportation linkages emanating from the source in figure 1 are coded to differentiate whether the link is carrying wastes or recoverables. The same coding system is used throughout the diagram. If source separated paper, cans and glass (or any other marketable commodity) are to be shipped to the market, then they flow along the clear linkage. If, on the other hand, mixed MSW or the residue from source separation is to be shipped, then flow occurs along the shaded linkage. Note that all wastes generated enter into transportation.

Each transportation, processing, and marketing activity has associated with it a set of costs. For transportation, these costs include the periodic replacement of the rolling stock as well as the cost of physically hauling the wastes or recoverables. The facilities where processing takes place require greater care in cost accounting. For example, there may be site preparation costs (e.g., access roads) over and above the plant construction costs and the normal costs of day-to-day operations. No economies of scale are assumed in transportation. However, economies of scale are admissible for both facility construction and all future processing activities. Thus, the model can capture the basic trade off of savings from centralized processing versus the costs of additional haul required to bring such savings about. In addition to costs, the appropriate capacity associated with a processing facility at a particular site (site-process combination) can be selected. The setting of a capacity can be based on either political or technical constraints. Setting a capacity would thus prevent the model from shipping to a single site more waste than would be technically or politically feasible.

Two types of markets are also shown in the diagram. RRPLAN treats the markets for energy (e.g., steam or electricity) and materials in a much more comprehensive manner than WRAP. RRPLAN can handle four types of market structure: (1) unlimited fixed price markets; (2) capacitated fixed price markets; (3) declining price markets with no upper limit; and (4) capacitated declining price markets. An example of an unlimited fixed price market might be an electric utility which will purchase any amount of electricity from the plant at a flat rate of 4¢ per kWh. An example of a capacitated declining price market might be a nearby industrial facility which will purchase process steam for $3 per K (thousand) lbs for the first 900 M (million) lbs; but will pay only $2 per K lbs for the next 900 M lbs; and can not productively use the steam above 1800 M lbs. The market is considered saturated at 1800 M lbs. RRPLAN also permits revenue sharing arrangements among municipalities to be incorporated into the market analysis.

The model approaches the difficult problem of siting and sizing solid waste processing facilities by first approximating non linearities in the capital and operating cost functions with up to three linear segments. Each segment has an intercept (a fixed charge) and a slope (an incremental cost associated with increased processing activities). The introduction of fixed charges imposes certain complications, due to the existence of local optima. Such circumstances require a specially designed optimization technique to generate meaningful solutions. The technique used in RRPLAN involves a fixed-charge linear programming algorithm with a forcing procedure meant to insure that the model can pass over an area of temporarily increasing cost in the solution domain (i.e., a local optimum) to find the true optimum (Walker [1976]). RRPLAN adds new forcing methods representing a significant improvement over methods used in other models (Berman, Chapman and Hung [1983]) in which each site (or site-process combination) which was in the solution is forced out of the solution and vice-versa. This approach permits the solution domain to be searched in a more coordinated way by operating on all activities (e.g., transportation, processing, marketing) associated with a particular site (or site-process combination). WRAP's method of single or double column (i.e., the activities described in table 2) forcing is of questionable efficiency, particularly where a site is linked to three or more sources or other sites.

Furthermore, column forcing operates from within the optimizer, so it is blind in the sense that there is no information within the optimizer on what the various columns (activities) represent.

Assuming that cost minimization is the sole objective of the decision maker, the problem to be solved by the optimizer may be stated as

$$\text{minimize} \quad Z = \sum_{j=1}^{n} f_j(x_j) \qquad \text{equation 1}$$

subject to the linear constraints

$$\underset{\sim}{A}\underset{\sim}{X} = \underset{\sim}{b} \qquad \text{(i)}$$

$$\underset{\sim}{X} > \underset{\sim}{0} \qquad \text{(ii)}$$

where

$$f_j(x_j) = c_j x_j + k_j \delta_j \qquad \text{(iii)}$$

with

$$\delta_j = 0 \quad \text{if } x_j = 0$$

$$\delta_j = 1 \quad \text{if } x_j > 0.$$

The vector $\underset{\sim}{X}$ contains n elements known as activities (e.g., shipments of MSW from a source to a site). The tilde is used to distinguish the vector, $\underset{\sim}{X}$, from the elements x_j. The matrix A contains m rows and n columns. (It is assumed that n is greater than m.) The rows refer to the equations defined in table 1 and the columns to the activities defined in table 2. The c_j in condition (iii) are variable costs and the k_j are the fixed charges. (The k_j values are required to be greater than or equal to zero. If the activity has no fixed charges, then k_j is equal to zero.)

RRPLAN as a Planning Tool: A Case Application for Central Mississippi

After preliminary testing of the RRPLAN model with data from New York City's Department of Sanitation and the California Solid Waste Management Board, the model was applied to data from a three county area surrounding the city of Jackson in central Mississippi. The primary objective was to determine how RRPLAN could be used as the basis for developing the economic requirements for a variety of municipal solid waste options which might be exercised in the Jackson area.

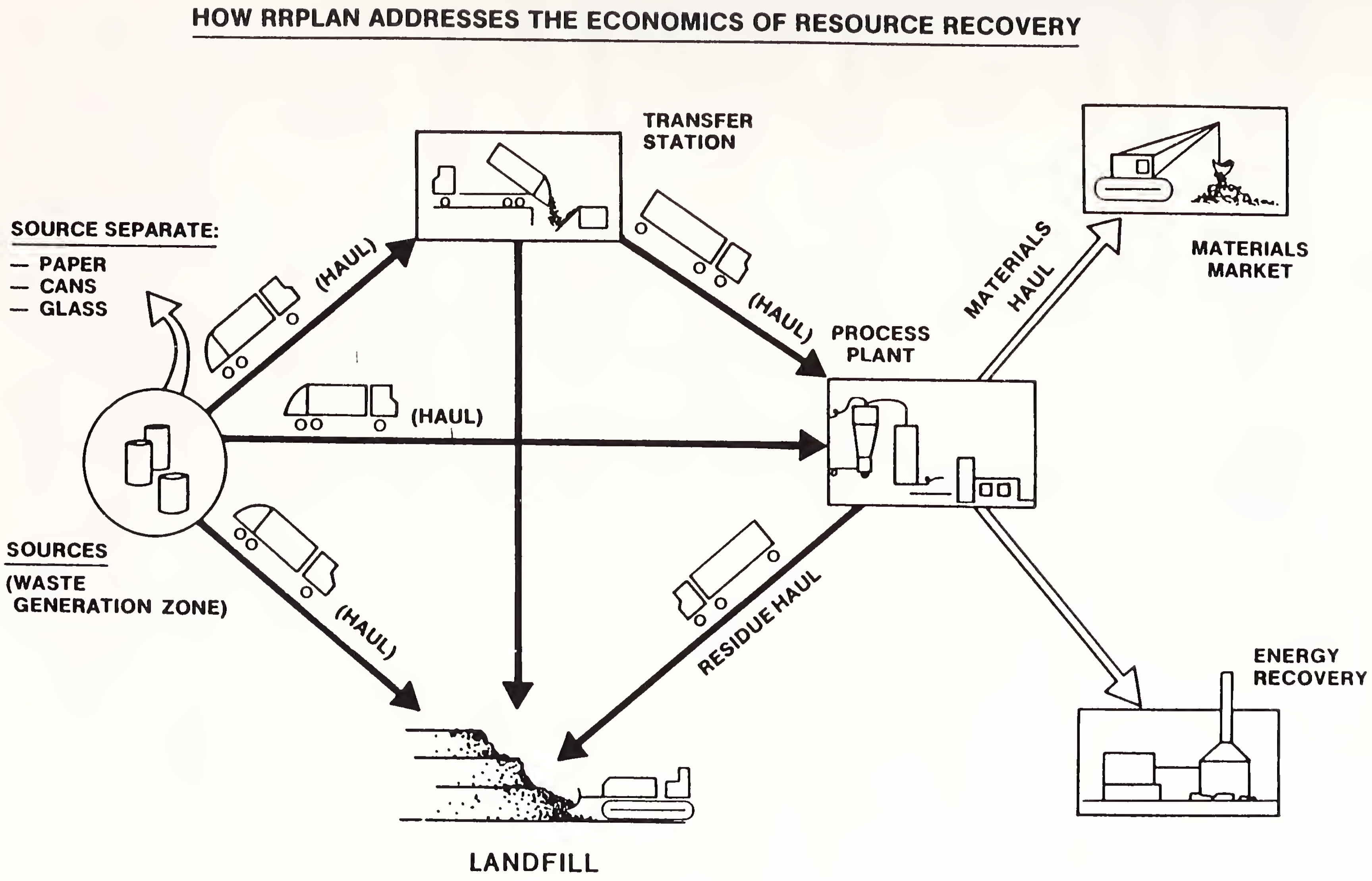
HOW RRPLAN ADDRESSES THE ECONOMICS OF RESOURCE RECOVERY
SOURCE SEPARATE:
— PAPER
— CANS
— GLASS
SOURCES
(WASTE
GENERATION ZONE)
(HAUL)
TRANSFER
STATION
(HAUL)
(HAUL)
(HAUL)
PROCESS
PLANT
MATERIALS
HAUL
MATERIALS
MARKET
RESIDUE HAUL
ENERGY
RECOVERY
LANDFILL

Figure 1 How RRPLAN Addresses the Economics of Resource Recovery

TABLE 1 Equations Used by RRPLAN

Equation Type	Purpose
Source balance equations	Requires all waste generated at each source to be entered into transportation.
Source paper balance equations	Requires all source-separated paper to be entered into transportation.
Site input residue balance equations	Generates a residue activity at a site equal to the residue arriving at the site.
Site input paper balance equations	Generates a paper activity at a site equal to the paper arriving at the site.
Site input balance equations for MSW and other commodities	Requires the total amount of MSW and other commodities arriving at a site to equal the amount of processing activity at the site.
Site output balance equations	Generates transportation activities of a commodity from a site equal to the process output of the commodity at that site.
Market input balance equations	Generates a total market activity equal to the amount of the commodity arriving at the market.
Site capacity constraints	Insures that processing at a site does not exceed capacity.
Land capacity constraints	Insures that land use does not exceed land available at any landfill.
Market bounds	Requires the sum of activity at a market in segments less than or equal to the jth $(1<j<5)$ segment to be less than or equal to the jth cumulative bound for the market.
Constraint on artificial processing activities	Provides an upper bound for artificial activities used to preserve the structure of the A matrix.

TABLE 2 Activities Considered by RRPLAN

Activity	Purpose
Transportation category 2	Site-to-site shipments.
Transportation category 3	Site-to-market shipments.
Transportation category 4	Source-to-site shipments of unseparated MSW.
Transportation category 5	Source-to-site shipments of unconditional source separated MSW (national paper market[a]).
Transportation category 6	Source-to-site shipments of unconditional source separated MSW (local paper market).
Transportation category 8	Source-to-site shipments of pre-separated paper (local paper market).
Transportation category 9	Source-to-market shipments of pre-separated paper (local paper market).
Transportation categories 11-15	Source-to-site shipments of conditional source separated MSW (national paper market) with 1 to 5 trigger prices.
Residue activities	Measures thousands of tons per year of source-separated residue arriving at a site.
Paper activities	Measures thousands of tons per year of source-separated paper arriving at a site.
Process activities	Measures number of commodity units processed per year per linear segment at a site.
Market activities	Measures number of commodity units purchased per year per linear segment at a market.
Artificial processing activities	Take on arbitrarily small values to preserve structure of the A matrix.
NZ	Relieves infeasibilities associated with an advanced starting point.
NZX	Relieves infeasibilities when evaluating a prespecified plan.

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[a] The nature of the paper market depends on whether the quantities of paper processed by the model will or will not affect the price. If the price is unaffected, then the market is designated as national. If the price is affected, then the market is designated as local.

Data on costs, markets, amount of MSW, inflation rates, and sites in the Jackson area were provided by the Bureau of Pollution Control of the Mississippi Department of Natural Resources. In summary, approximately 360 thousand tons per year (KTPY) of MSW were calculated to be generated in the area. Steam and/or electricity from a potential waste-to-energy facility could be marketed — steam to the packing industry and electricity to the local untility. Source separation was not to be implemented regionally; there was litle or no market for recovered materials except aluminum. Landfill could be used if necessary (i.e., siting could be accomplished). Financing for a waste-to-energy facility could probably be obtained at a 10 percent rate for a 15 year term; the useful life of the facility was anticipated to be 20 years.

The first task for RRPLAN was to estimate the cost of an all landfill-no recovery option given collection costs, disposal costs, land costs and labor and transportation costs in the Jackson area. This computation was meant to provide a datum against which all other options could be compared. RRPLAN computed the discounted cost of this option as $21.20 per ton for the 20-year period beginning January 1, 1985 and ending December 31, 2004. This cost can be interpreted to mean that it would take $21.20 of money at January 1, 1985 value to collect, transport, and dispose of one ton of Jackson area MSW (i.e., all MSW for 20 years could be disposed at this discounted cost). All subsequent RRPLAN claculations were discounted on the same basis. Hence, in what follows, all costs are on the same basis (i.e., discounted to a present value as of January 1, 1985). A cost difference between two options of $1 per ton on this basis results in a $7.2 million cost difference for the total of 20 years since 20 years times 360 KTPY is 7.2 million tons of MSW.

A waste-to-energy facility was then considered at a site in the city of Jackson. In the absence of such a plant, eight landfills in the tri-county region surrounding Jackson would continue to receive 360 KTPY of MSW at a discounted cost of $21.20 per ton. Once the new facility was in place, RRPLAN predicted that about 300 KTPY of waste could be processed there. Several landfills would cease operations; the remainder of the MSW would go to the rest. RRPLAN never predicted that siting, construction and use of transfer stations would be economically advantageous for the Jackson area. Note that RRPLAN selects the optimum activity level for each site (i.e., waste tonnage) and the most economical transportation linkages to utilize these sites. For an input of 300 KTPY, facility capacity needs to be about 1150 tons per day.

A sensitivity analysis was then performed to determine how variations in the capital cost of the facility and anticipated revenues would affect the discounted cost per ton. Two basic scenarios were analyzed. The first was based on steam sales to the packing industry. The second was based on electricity sales to the local utility. For both scenarios, we assumed that one ton of MSW would yield either 6 MBTU (million BTUs) of steam or 625 kwh of electricity for delivered use. These figures assume an incinerator efficiency of 67 percent for steam conversion and a turbine efficiency of 35.6 percent. The results of the sensitivity analysis are summarized in tables 3 and 4. The steam and electricity revenues shown in these tables should be viewed as representing likely ranges for the facility rather than negotiated contract values.

The data from tables 3 and 4 were fitted using the ordinary least squares routine of the DATAPLOT statistical analysis package (Filliben [1982]). In both cases, the response variable was the discounted cost per ton. The explanatory variables were: (1) an intercept term constrained to a value of \$21.20, representing the cost of the all landfill option; (2) the capital cost of the facility in millions of dollars; and either (3) the revenue per MBTU of steam output; or (4) the revenue per kwh of electricity output. The estimated values of these relationships are shown in equations 2 (steam) and 3 (electricity):

$$DC_S = 21.20 + \underset{(65.55)}{0.118 \cdot CAP_S} - \underset{(-68.34)}{2.775 \cdot REV_S} \qquad \text{equation 2}$$

and

$$DC_E = 21.20 + \underset{(29.35)}{0.129 \cdot CAP_E} - \underset{(-31.42)}{2.749 \cdot REV_E} \qquad \text{equation 3}$$

where

DC_* = discounted cost per ton;

CAP_* = capital cost of the facility in millions of dollars;

REV_* = revenue per unit of output delivered; and

$*$ = S (steam) or E (electricity).

The values in parenthesis beneath each coefficient are the t-statistics associated with the fit. The importance of the explanatory variables is reflected in the high values of the t-statistics. A cursory review of equations 2 and 3 indicates that the coefficients have the proper signs and assume values which are of the same order. However, an important difference is that, other things being equal, the discounted cost of the electricity supplying facility is somewhat more sensitive to changes in capital cost and less sensitive to changes in revenues.

If ST_* ($*$ = S or E) is designated as the savings per ton of MSW handled as compared to the all landfill option, then

$$ST_* = 21.20 - DC_* \qquad \text{equation 4.}$$

The value for DC_S (equation 2) or DC_E (equation 3) may then be inserted into equation 4. If ST_* is positive, then the recovery option is more economical than the all-landfill option. Conversely, if ST_* is negative, then the recovery option is less economical than the all landfill option. A value of ST_* equal to zero defines the break-even point between the landfill and recovery options. The break-even points, in terms of revenue per unit of output, for each type of recovery facility are given by equations 5 (steam) and 6 (electricity):

Table 3 Discounted Cost Per Ton of MSW Processed for a Waste-to-Energy Plant Supplying Steam

STEAM REVENUES[a]	FACILITY COST IN MILLIONS OF DOLLARS 75	85	100
2.50	23.16	24.27	25.93
3.33	20.93	22.04	23.71
4.17	18.70	19.81	21.48
5.00	16.08	17.20	18.87

[a] Dollars per MBTU.

Table 4 Discounted Cost Per Ton of MSW Processed for a Waste-to-Energy Plant Supplying Electricity

Electricity Revenues[a]	FACILITY COST IN MILLIONS OF DOLLARS 80	90	100	110	120
4	21.21	22.33	23.44	24.55	25.66
5	18.03	19.14	20.25	21.37	22.48
6	15.19	16.30	17.42	18.53	19.64

[a] Cents per kwh.

$REV_S = (0.0425) \cdot CAP_S$ equation 5

and

$REV_E = (0.0469) \cdot CAP_E$ equation 6.

Break-even points for five capital cost figures are summarized in table 5. As may be seen in equations 5 and 6, the revenues required to break even are more sensitive to changes in the capital cost of the electricity producing facility.

Table 5 Break-Even Points for Selected Capital Outlays

TYPE OF FACILITY	FACILITY COST IN MILLIONS OF DOLLARS				
	80	90	100	110	120
STEAM[a]	3.40	3.83	4.25	—	—
ELECTRICITY[b]	3.75	4.22	4.69	5.16	5.63

[a] Dollars per MBTU in revenue required to break-even.

[b] Cents per kwh in revenue required to break-even.

Since the turbine represents a considerable additional first cost, the cost of a facility to generate electricity is likely to be higher than that of a facility to generate steam. Thus the value of $DC_E - DC_S$ is of interest in evaluating the additional initial risk:

$DC_E - DC_S = (0.129 \cdot CAP_E - 0.118 CAP_S) - (2.749 \cdot REV_E - 2.775 \cdot REV_S)$ equation 7.

Equation 7 may now be used to calculate the affordable extra turbine costs for any given value of $DC_E - DC_S$ which is deemed to make the risk acceptable. In general, if a firm value of REV_E is available, then the revenue per MBTU of steam to be equivalent is:

$REV_S = -(0.046 \cdot CAP_E - 0.043 \cdot CAP_S) + 0.360 \cdot (DC_E - DC_S) + 0.991 \cdot REV_E$

equation 8.

If, on the other hand, a firm value of REV_S is available, then the revenue per kwh of electricity to be equivalent is:

$$REV_E = (0.047 \cdot CAP_E - 0.043 \cdot CAP_S) - 0.364 \cdot (DC_E - DC_S) + 1.009 \cdot REV_S$$

equation 9.

Thus, a complete risk analysis for any reasonable baseline scenario can be performed in terms of the market prices for steam and electricity as well as for the capital cost of the facility. It is important to point out, however, that all of these calculations assume that approximately 300 KTPY will actually be processed at the facility, and that all of the energy recovered from the MSW processed can be sold. The effect of changes in the baseline tonnage processed ($KTPY_b$) on the discounted cost per ton remains to be analyzed.

In order to compute the relationship, and hence sensitivity of DC_* to the baseline tonnage processed, the following equation may be used:

$$DC_* = a + b \cdot (CAP_*/KTPY) + c \cdot RPT_* + \varepsilon \qquad \text{equation 10}$$

where RPT_* = the revenue per ton of MSW input; and
ε = a (stochastic) disturbance term.

If a tipping fee is charged per ton of MSW input, then its value would be incorporated into RPT_* along with any revenues from steam or electricity sales. The values of a, b and c in equation 10 are functions of the RRPLAN input data (e.g., discount rate, terms of loan, useful life of the facility).

The analysis of the central Mississippi case study indicates that

$$DC_* = 21.20 + \beta_* \cdot (CAP_*/KTPY) - 0.449 \cdot RPT_* \qquad \text{equation 11}$$

where $\beta_* = 39.50$ if $* = E$ (electricity); or
34.37 if $* = S$ (steam).

As in the previous cases, a, has been constrained to a value of $21.20, the discounted cost per ton for the all-landfill option.

Equations 10 and 11 closely resemble the one suggested by Yakowitz [1981] for the approximate break-even cost for any resource recovery facility. The crucial difference is that equation 10, if based on results from RRPLAN, represents fully discounted dollars over the lifetime of the facility whereas the relation given by Yakowitz represents current dollars for the first year of a publicly owned facility.

The relationship given in equation 10 is a general economic expression governing resource recovery or most other businesses where a product is produced via the use of capital equipment and sold on a per unit basis. For the case of resource recovery, one wishes to minimize the values of a, b and c. In effect, the fixed-charge linear programming algorithm of RRPLAN implicitly selects values for a, b and c, given the problem structure imposed by the input data, so as to minimize DC*. However, uncertainties in a, b and c depend upon:

(1) the mathematical formulation of the problem;
(2) the algorithm used to implicitly solve for the optimal mix of a, b and c;
(3) the input data (e.g., discount rate, inflation rate, useful life of the capital stock, transportation network); and
(4) the stochastic nature of a, b and c (e.g., as reflected by the width of the confidence intervals about the predicted values).

If all variables in equation 10 are subject to uncertainty, then the total differential may be used to approximate the risk associated with the baseline values:

$$\Delta DC_* = a\cdot(\Delta a/a) + b\cdot(CAP_*/KTPY)\cdot[\Delta b/b)+(\Delta CAP_*/CAP_*)-(\Delta KTPY/KTPY)] + c\cdot RPT\cdot[(\Delta c/c)+(\Delta RPT/RPT)] \qquad \text{equation 12}$$

The first, second and fifth Δ ratio terms of equation 12 are associated with uncertainties in the estimates of a, b and c. The other Δ ratio terms are associated with uncertainties in the input data. Note that uncertainties in the input data will affect the estimates of the parameters a, b and c. These effects will be of a second order nature, however, and are modeled through the inclusion of the stochastic term in equation 10.

Equation 12 is a capsule summary of the economic and technical challenges facing planners and decision makers in selecting the best resource recovery scenario. Through reference to this equation, local planners can assess the effect of specific uncertainties on the economics of any resource recovery scenario. For example, if only KTPY can vary, then equation 12 becomes

$$\Delta DC_* = - b\cdot(CAP_*/KTPY)\cdot(\Delta KTPY/KTPY) \qquad \text{equation 13}$$

where the minus sign in equation 13 indicates that a decrease in tonnage will result in an increase in the discounted cost per ton, DC*. For example, if the capital cost of the facility was $100 million and 300 KTPY were to be processed, then a decrease of 15 KTPY would result in an increase of approximately 50 cents per ton for a steam-producing facility or 60 cents per ton for an electricity-producing facility.

A closer examination of equation 12 is now in order. If a nominal revenue of $30 per ton is assumed along with a five percent range on each variable and a two percent range on each of the three parameters (based on the width of their 90 percent confidence intervals), then the increase in discounted cost could be as high as $3.00 per ton, or 15 percent of the estimated value of the discounted cost per ton. Hence, for purposes of planning, the uncertainty can perhaps be approximated by a figure of 20 percent. Thus, if a combination of costs, tonnages and income can be obtained such that RRPLAN predicts a reduction in DC$_*$ of \$3 to \$4 with respect to the all landfill option (which is also subject to similar uncertainty calculations), then the risk associated with investing in the resource recovery facility is probably worth serious consideration. Although equation 12 provides valuable information on how costs may vary due to uncertainty, it does not yield an explicit measure of risk. In order to remedy this deficiency, a series of Monte Carlo experiments were performed. The three explanatory variables (CAP$_*$, RPT$_*$ and KTPY) in equation 11 were the focus of the experiment. Based on previous work on probabilistic cost estimation (Vergara [1977]), the capital cost of the facility, CAP$_*$, was assumed to be lognormally distributed with a mean of \$85 million and a standard deviation of \$7 million for the facility serving the steam market and a mean of \$105 million and a standard deviation of \$10 million for the facility serving the local utility. The lognormal distribution is particularly attractive for large construction projects because it is asymmetric. Consequently, the lognormal distribution explicitly allows for low-probability high-cost events. Since the revenue per ton, RPT$_*$, is dependent on the outcome of contract negotiations, we assumed that the revenue per unit (i.e., per MBTU or kwh) was uniformly distributed. For a uniform distribution, each value within the range is equally likely. The range considered was \$2.50 to \$6.00 per MBTU for steam and 4¢ to 6¢ per kwh for electricity.

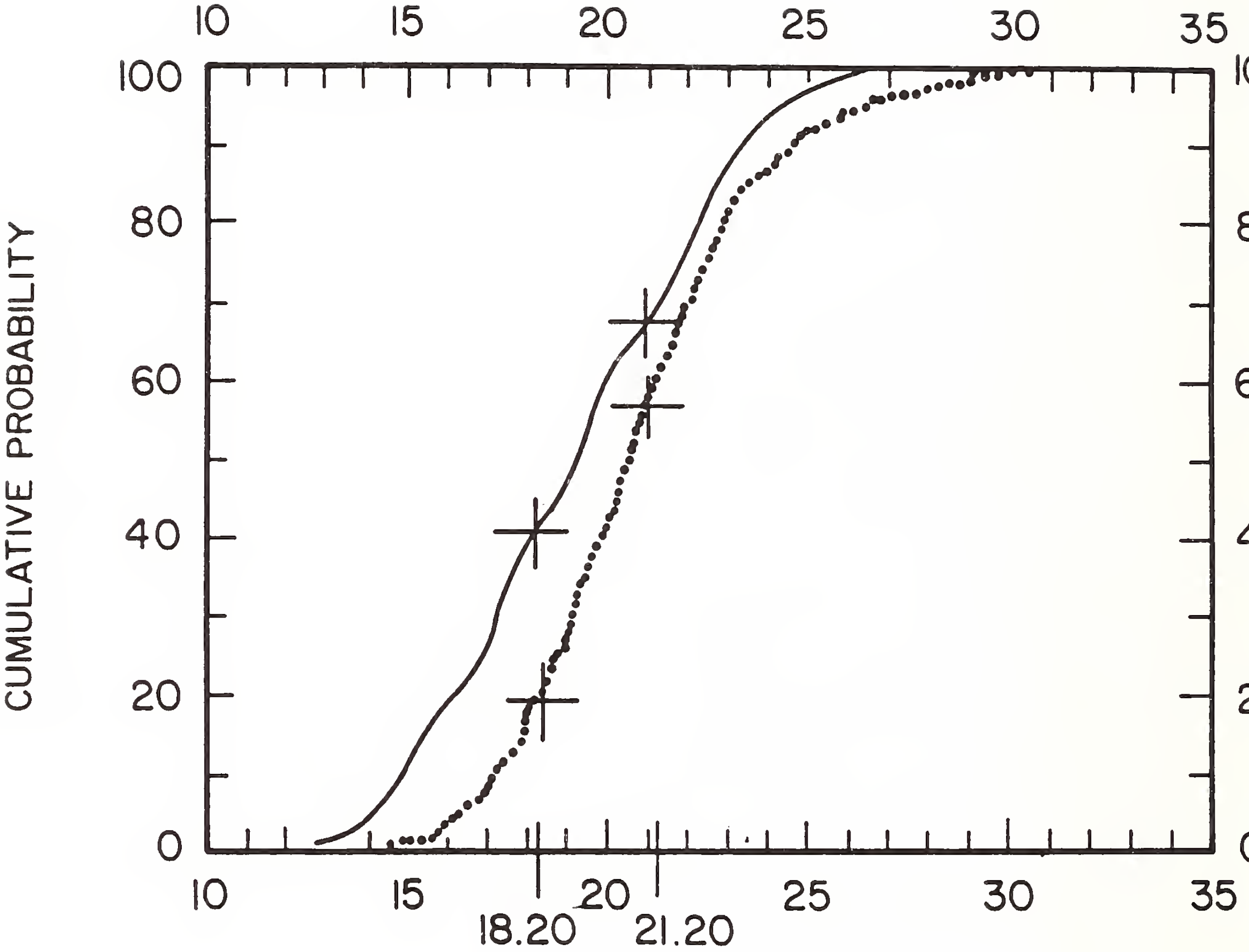
The treatment of random variations about the volume of waste processed is more complicated since the rate of waste generation may increase. Two scenarios were thus hypothesized. In the first, the amount of MSW processed was assumed to be normally distributed with a mean of 300 KTPY and a standard deviation of 30 KTPY; this case corresponds to a "No Growth Scenario". In the second, the amount of MSW processed was assumed to be lognormally distributed with a mean of 300 KTPY and a standard deviation of 40 KTPY, this corresponding to a "Growth Scenario". A lognormal distribution was selected for the growth scenario because it shifts the bulk of the probability distribution towards higher rates of processing (e.g., more waste is generated, so more is available for processing). The standard deviation was increased from 30 to 40 KTPY to highlight the uncertainty associated with such growth projections.

The Monte Carlo experiments were carried out through application of the NBS DATAPLOT statistical analysis package. As a first step, a vector of random numbers from the standard forms for each of the three probability distributions were generated. Vectors of length 100, 200 and 500 were tried to assess the impact of sample size on the results. A qualitative analysis of the experiments indicated that the results were relatively insensitive to sample size. The random numbers were then used to generate a vector of random values for CAP$_*$, KTPY and RPT$_*$ based on the ranges and parameter values given earlier. These values were then inserted into equation 11. The resultant estimates of discounted cost per ton were then sorted from smallest to largest. The ranked estimates (i.e., order statistics) were then used to construct a frequency based probability distribution.

For a given value of discounted cost per ton, dc, such a distribution shows the probability that the "true" cost will fall below dc. If dc is taken to be the cost of the all-landfill option, then the experiment shows the probability that the cost of the waste-to-energy facility will fall below the all-landfill option. A similar statement can be made for a selected risk margin (say $3, or a value of dc equal to $18.20). The results of the Monte Carlo experiment based on a sample size of 500, are summarized in figures 2 and 3. Figure 2 presents the results of the no-growth scenario experiment; figure 3 summarizes the growth scenario experiment. The horizontal axis of each figure records the discounted cost per ton, whereas the vertical axis records the probability that discounted cost falls below the estimate.

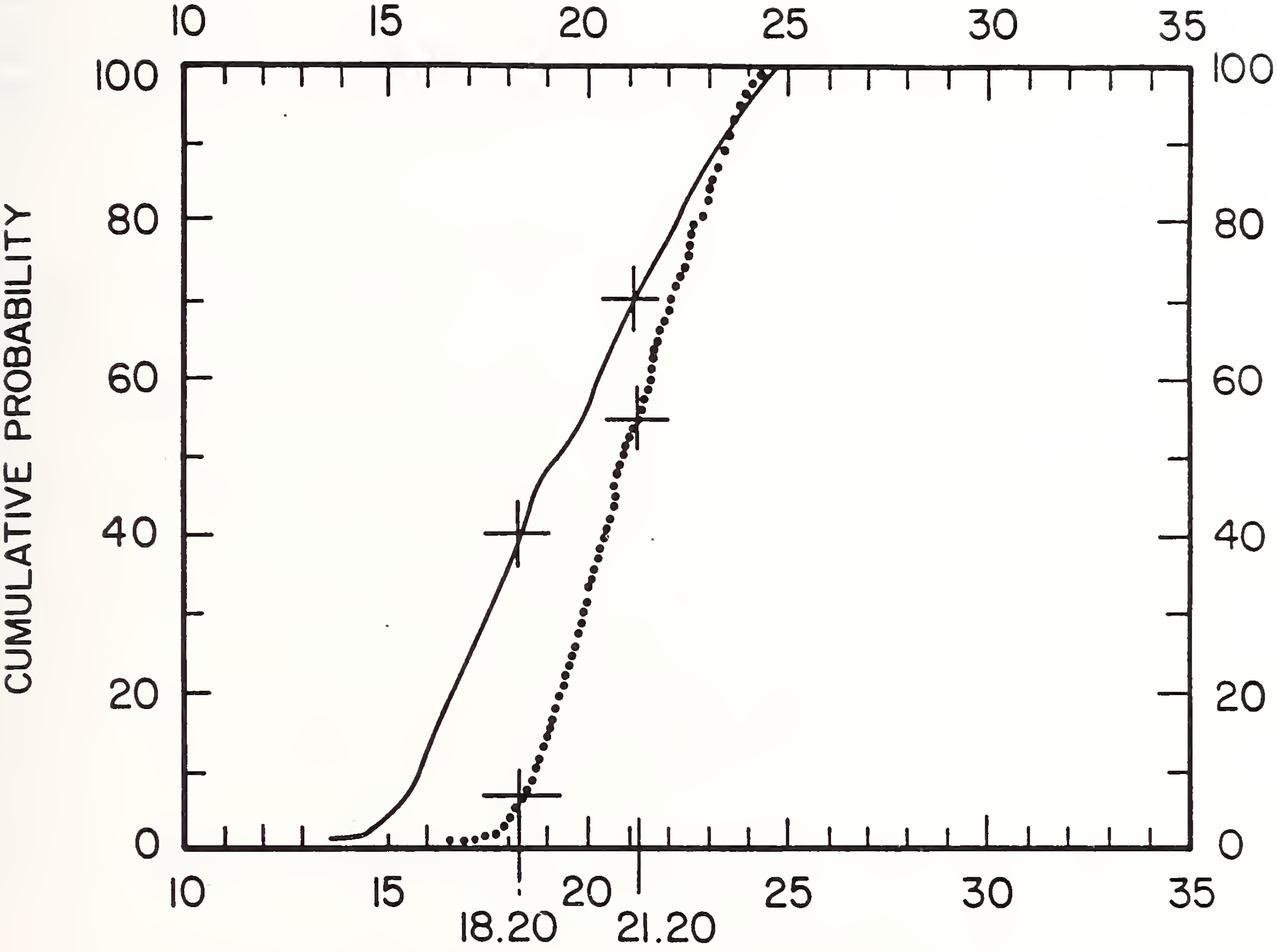
An examination of figure 2 reveals several important points. First, the discounted cost per ton for the facility producing steam is always less than the discounted cost for the facility producing electricity. The major reasons for this difference are the magnitude of the capital outlay ($105 million vs $85 million on the average) and the size of the β coefficient in equation 11 (i.e., $\beta_E > \beta_S$). Second, if the discounted costs for each facility are compared to those of the all-landfill option, the facility generating steam has a probability slightly in excess of 0.7 that the incurred costs will fall below the $21.20 figure. The facility generating electricity, on the other hand, has a corresponding probability of approximately 0.6 (i.e, investment in the electricity generating facility is about 15 percent more risky than investing in the steam generating facility). Third, the $3 margin (i.e., a discounted cost of $18.20) can be achieved with a probability of slightly over 0.4 if the facility which generates steam is selected. If the facility which generates electricity is chosen, however, the probability is reduced to a value of approximately 0.15. These figures imply that investment in a steam generating facility could be expected to better the $3 margin 40 percent of the time, whereas investment in the electricity generating facility could be expected to better the $3 margin only 15 percent of the time. Finally, highly unprofitable events can occur with both types of facilities. For example, the probability of exceeding a discounted cost of $22.00 per ton is 0.2 for the steam generating facility and 0.3 for the electricity-generating facility.

When the rate of generation of the waste stream is allowed to grow, a slightly different picture emerges. Figure 3 shows that the probabilities that the facilities will incur costs below the $21.20 figure are virtually unchanged at 0.7 for steam and 0.6 for electricity. This result may be explained in part by noting that a switch from the normal to the lognormal distribution was made for the volume of MSW produced. The ratio of two lognormal (CAP/KTPY) distributions can be converted to a normal distribution through a non-linear transformation of variables. The variance resulting from the transformation is the sum of the variances of the two distributions. The symmetry of the normal distribution and a slightly tighter variance (hence standard deviation) therefore tends to reduce the maximum and increase the minimum values of DC. The changes are not in the same proportion, however. Since KTPY enters equation 11 in the denominator, equal increases above 300 KTPY will result in smaller changes in DC than will equal decreases below 300 KTPY. Both



DISCOUNTED COST IN DOLLARS PER TON PROCESSED
SOLID = STEAM; DOTTED = ELECTRICITY
OUTPUT OF 6 MBTU OR 625 KWH PER TON OF MSW INPUT

FIG. 2 RISK ASSESSMENT FOR STEAM VS ELECTRICITY
(NO GROWTH)



DISCOUNTED COST IN DOLLARS PER TON PROCESSED
SOLID = STEAM; DOTTED = ELECTRICITY
OUTPUT OF 6 MBTU OR 625 KWH PER TON OF MSW INPUT

FIG. 3 RISK ASSESSMENT FOR STEAM VS ELECTRICITY
(GROWTH SCENARIO)

probability distributions are therefore steeper than their no-growth counterparts. With regard to the $3 margin, the steam-generating facility still has a probability of 0.4 of incurring costs less than $18.20, whereas the electricity generating facility has fallen to a probability under 0.05.

The data shown in the two figures thus provide a strong argument in favor of the facility supplying steam to the local packing industry. The decision of whether or not to proceed with a resource recovery facility should also include a similar analysis of the costs of landfilling. Such an analysis, based on a coordinated set of RRPLAN runs, would establish the likely lower and upper limits on the discounted cost for the all-landfill option. These costs could then be compared with those presented in figures 2 and 3 to determine if the steam-producing facility was still competitive.

Concluding Remarks

The role of RRPLAN in assessing resource recovery options can be summarized as follows:

(1) RRPLAN identifies a minimum cost plan by comparing the various DC_* values for each option.

(2) In every case, the optimizer minimizes individual DC_* values as a function of the specific input data offered by the user.

(3) RRPLAN does not compute unique values for the variables a, b, and c in equation 10.

(4) By varying the input data to RRPLAN, specific estimates for a, b, and c, as well as preliminary estimates for the uncertainties in these variables can be obtained. RRPLAN probably provides the best available means to predict a, b, and c accurately.

(5) Equation 12 represents the "risk evaluator" for a specific set of data and the uncertainties in these data.

(6) A planning basis for a waste management strategy is incomplete until all terms in equations 10 and 12 are evaluated numerically for various options.

Thus, RRPLAN, if used properly, provides the foundation for planning. But considerable additional assessment may well be necessary in order to choose the proper strategy for a given region. This assessment involves probabilistic estimation for the input variables (discount rate, costs, etc.), followed by multiple RRPLAN evaluations. The results will provide values for all terms in equations 10 and 12. Unless all of these steps are taken, RRPLAN results need to be treated with extreme caution. The lack of a coordinated approach or reliance on outmodel or inaccurate data significantly increases the risks of adopting a resource recovery plan. The U.S. has had several cases where resource recovery options have not lived up to proponents' expectations. RRPLAN and the approach outlined in this paper provides an opportunity to avoid some of these pitfalls.

RRPLAN, as developed for and by the National Bureau of Standards' Office of Recycled Materials, represents an appropriate means to begin evaluation of specific resource recovery options for a city, state, or region. The input data requirements will tend to require the prospective RRPLAN client to determine each item of data as accurately as possible. Careful data assessment, intelligent use of RRPLAN and solutions to equations 10 and 12 should help to reduce the risk associated with resource recovery. In turn, the data gathering process and the subsequent RRPLAN and probablistic analysis should clearly highlight potential or actual institutional problems.

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report is meant to serve two purposes: (1) Summarize the activities and accomplishments of the Office of Recycled Materials of the National Bureau of Standards (NBS/ORM) undertaken in response to legislative directives from 1976 through 1982; (2) Provide a compilation of FY 1982 activities of NBS/ORM.

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